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Adama Science and Technology University

School of Electrical Engineering and Computing

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Performance Analysis of Radio Frequency Propagation Models in UMTS Network (a case study on Adama city)

By

Firew Tadele

A thesis Submitted to School of Electrical Engineering & computing in partial fulfillment of the requirements for the degree of Master of Science, in Communication Engineering

Advisor: Dr. M. Venkata Raghuvandra

ADAMA, ETHIOPIA

June 2017

Declaration

I hereby declare that the work which is being presented in the thesis entitled**,** Performance Analysis of Radio Frequency Propagation Models in UMTS Network in Adama city**,** submitted to Adama Science and Technology University (ASTU) in partial fulfillment of the requirements for the degree Master of Science in Communication Engineering, is the result of my own research carried out under the supervision of Dr. M.Venkata Raghuvandra and all material used and reproduced has been properly referenced.

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This is to declare that the above statement made by the candidate is correct and true to the best of my knowledge.

Signature:

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Abstract

This thesis shows an analysis about RF signal propagation models in Third Generation mobile networks, their access medium is Wideband Code Division Multiple Access. The research includes field measurements and the choice of six propagation models with technological and environment of the test area. With a computer algorithm, select one of six outdoor propagation models for the study area and compared results of field measurements versus selected models.

The study was made in an environment with a high population density and a high demand of data traffic (urban areas), suburban and rural areas of Adama city; selected twelve Base Stations (Nodes B) out off this four Node B's for urban areas, four for suburban and four for rural areas in a test area with the objective of observe real behavior of signal transmitted versus ideal behavior of an empirical method.

The observed result of the measured path loss compared with other existing path loss prediction methods and found that the Okumura-Hata model path loss values were closest of all the propagation models considered classifying the environment into consideration. Thus, the performance of Okumura-Hata model shows its suitability for path attenuation loss prediction in UMTS networks in Adama city. The Lee model also has the least path loss for all of the chosen RF propagation models, but it's mainly applied for the operating frequency of 900 MHz not 2100 MHz and this model specially applied for rural areas and Adama city is one of the fastest growing cities of the country.

Acknowledgments

First and foremost, I would like to offer my sincerest gratitude to my advisor Dr. M.Venkata Raghuvandra), who has supported me throughout my thesis and encouraging me to work in my own way, and given me the freedom to research issues i have found relevant. This thesis would not have been possible without the help of him.

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Finally I would like to express my special thanks to my families, my wife and friends who always motivate and support me to complete this thesis, and I am thankful for those who stood by me throughout my work, giving me encouragements and valuable help.

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List of Acronyms

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	Third Partnership Project
4G	Fourth Generation
5G	Fifth Generation
AICH	Acquisition Indication Channel
AMC	Adaptive Modulation and Coding
AUC	Authentication Center
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BER	Bit Error Rate
BPSK	Binary phase-shift keying
BSC	Base Station Controller
BTS	Base Transceiver Station
CCCH	Common Control Channel
CDMA	Code Division Multiple Access
CPCH	Common Packet Channel
CPICH	Common Pilot Channel
CTCH	Common Traffic Channel
CN	Core Network
COST	European **Co**-operation in the Field of **S**cientific and **T**echnical research
CS	Circuit Switch
CSICH	CPCH Status Indication Channel
DCH	Dedicated Channel
DL	Down Link
DS-CDMA	Direct Sequence CDMA
DSCH	Downlink Shared Channel
DTCH	Dedicated Traffic Channel
Ec/No	Energy per Carrier over Noise density

EDGE	Enhanced Data rate for GSM Evolution
FACH	Forward Access Channel
FDD	Frequency Division Duplex
Gbps	Giga bits per Second
GGSN	Gateway GPRS Support Node
GMSC	Gateway MSC
GPRS	General Radio Packet System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HARQ	Hybrid ARQ
HLR	Home Location Register
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access (HSDPA + HSUPA)
HSUPA	High Speed Uplink Packet Access
IMT-2000	International Mobile Telecommunications-2000
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISI	Inter Symbol Interference
ITU	International Telecommunications Union
KPI	Key Performance Indicator
LTE	Long Term Evolution
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MSC	Mobile Switching Centre
OFDM	Orthogonal Frequency Division Multiplexing
OVSF	Orthogonal Variable Spreading Factor
QoS	Quality of Service
QPSK	Quaternary Phase Shift Keying
PCH	Paging Channel
PLMN	Public Land Mobile Network
PS	Packet Switch

PSTN	Public Switched Telephone Network
RAN	Radio Access Network
RNC	Radio Network Controller
RRC	Radio Resource Control
RRM	Radio Resource Management
RSCP	Received signal code power
SCH	Synchronization Channel
SGSN	Serving GPRS Support Node
SIR	Signal to Interference Ratio
SNR	Signal to Noise Ratio
TDD	Time Division Duplex
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrial Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband code division multiple access
WiMAX	Worldwide Interoperability for Microwave Access

Chapter one

1 Introduction

The set of wireless technologies, especially those related to communication have evolved quickly. Mobile communications have become the best partner of people, helping them to complete daily tasks and making this a better and comfortable experience. The development of mobile technology in third generation (3G) is a global engagement work always focused on improving services quality, all under supervision of work groups, these groups carry out compliance with international standards and protocols, especially created to support 3G technology.

The cellular network is most popular type of wireless networks. It is a combination of small cells and it can provide better network coverage with increasing number of users. The quality of service and mobility management is also improved in cellular networks. In a wireless transmission the quality of signal, degrades due to the fading effects in channel caused by the multipath propagation. In order to reduce these effects, cooperative communications are one of the best methods. The cooperative communication may employ path diversity to transfer the signal from source to destination. Some important factors in any kind of wireless communication system are signal propagation and losses through the physical environment from one place to another. Therefore, mobile services providers use this factor for planning and distributing equipment and if this way they can satisfy the minimum conditions for establishing a good communication [1].

Cellular phone networks are the most widely used systems all over the world. In order to efficiently plan new communication networks and improve the existing networks, accurate radio frequency (RF) path loss models are required. Although various models are available, only some of these models will match the area considered because every model was derived from measurements performed for certain area conditions. Therefore, this thesis needs to determine an appropriate model that can accurately predict the path losses in Adama city, Ethiopia.

Integration of multimedia transmission and broadband internet access in mobile systems has increased traffic dramatically. This demands that operators perform their cell planning process in a manner that will produce a precise cell arrangement to fulfill performance requirements subject to economic constraints. Moreover, the deployment of efficient transmission, operation, and management technologies accompanied by continuous reduction in size of cells requires better precision in the estimations of the network coverage. This is given by propagation losses, in order to attain comprehensive coverage with which the operator aims to guarantee quality of service.

Wireless network planning tool modeling parameters conform closely to the actual environment, clutter, terrain, in addition to their topologies, the predicted path loss values and hence predicted coverage maps will deviate greatly from the actual ones. Hence, field measurements, study, and analysis to investigate the effects of a specific topography for a particular region or a country is necessary to arrive at realistic values of path loss predictions in the currently utilized software planning tools. This is reflected in propagation model calibration relying on field measurements, which is an essential step in optimizing propagation model parameters to achieve minimal error between predicted and actual signal strengths.

UMTS network planning is much more complex than GSM network planning. Since in UMTS/HSDPA it is not a matter of simple minimum received signal level to achieve one maximum interference threshold; In UMTS, each service needs a specific threshold value. In addition, general network performance and behavior changes with traffic. Moreover, propagation models used to predict GSM 900/1800 systems coverage do not apply directly to the 2100 MHz frequency band [2, 3].

Recently, a new air-interface, namely WCDMA, is being deployed on existing GSM core network in our country, Ethiopia with the objective of offering more efficient mobile data services. The initial coverage is mostly concentrated in urban, densely populated, and high-income areas. The need for an accurate propagation prediction tailored to Ethiopia is important to complete the rollout phases and achieve optimal coverage in desired areas. That is because Ethiopia offers a uniquely various different construction materials and landscape.

The study showed in this thesis was realized in urban, suburban and rural environments of Adama city, Ethiopia. The deployment of 3G services still predominate in the area and 4G technologies are in a first stage especially in Addis Ababa city, Ethiopia.

This thesis presents its efforts and investigation of an appropriate propagation models for useful adaptation in the deployment of 3G service in Adama city, Ethiopia. It also intended to find a radio frequency propagation model that can correctly predict the path loss in the environment and extend this model to other areas of the region (SER). To that end, various path loss models are compared with extensive measurements, at the 3G networks that have been performed in different areas of Adama, Ethiopia.

The thesis is aimed at calculating path attenuation loss at the mobile terminal via measured field strength propagation data in a 3G based UMTS network using a local telecom service provider called Ericsson. It transmits at a frequency of 2100MHz in the Adama city (South East Region), Ethiopia. This is to enable us obtain the most suitable path loss prediction model from among the existing ones for mobile radio signal propagation in the study area.

1.1 Background

Ethio-Telecom is a government owned Telecom Company born from the ambition of the Ethiopian government to provide a world-class telecom services for the country and serve the Ethiopian citizen by being a customer centric company. The mobile communication services were introduced in the year 2000 using 2G Global System for Mobile Communications (GSM) standard and network equipment were supplied by Ericsson and Nokia Siemens and initial deployment done for the city of Addis Ababa and by 2005, the network was expanded to cover tourist destinations (regional areas) across the country[4].

In 2007, as part of the *Ethiopia Millennium Project*, the next generation network (NGN) was launched to expand and upgrade Ethiopia's network, which also includes the associated rollout of mobile coverage in *rural areas* and was deployed by ZTE Company. The NGN project introduces new technology, system application and services such as 3G WCDMA and CDMA 2000 mobile network infrastructures (3G available in Addis Ababa), call center, billing system and value added services (CRBT, GPRS, NNOC and short code services). As a result of these expansions, the number of mobile subscribers has exponentially increased and the prevailing data indicates over 20 million subscribers. With increasing demand for wireless services, the capacity of 2G and 3G networks is reaching saturation point.

To deal with the shortage of mobile network resources, 3GPP has proposed Long Term Evolution (LTE), and this is now developing from theory into practice [5] and Ethio-telecom introduced this technology for Addis Ababa to achieve the goal of Growth and Transformation Plan (GTP 2) of the country [6]. With powerful service bearing capability, efficient resource utilization, low network construction and operation costs, and flexible network deployment, LTE has won favor from leading operators around the world. With 3GPP freezing Release 8 in 2015, LTE standards are now in a mature state.

LTE systems adopt advanced radio link technologies in the air interface, including orthogonal frequency division Multiplexing (OFDM), multiple-input multiple-output (MIMO), adaptive modulation and coding (AMC), and Hybrid Automatic Repeat reQuest (HARQ) [7,8,9]. From the perspective of LTE network design, these technologies and algorithms improve network performance but increase system complexity as well.

In its first Growth and Transformational Plan (GTP I), the Government of Ethiopia set out its vision, objectives, and targets to extend the mobile phone subscriber from 6.5 million to 40 million and to reach service coverage of 90% by the end of 2015. Delivering this vision, and meeting the ambitious targets for coverage and service quality, will require significant efforts from Ethio-telecom to initiate and manage huge telecom expansion projects.

In aligning with this objective Ethio-telecom signed off telecom expansion project deal with Chinese vendor, Huawei, in august 2013 with the commitment to finish the mobile network rollout for the capital city, Addis Ababa, within nine months' time and also Ethio-telecom signed off this project with other vendors like Ericsson for 4 circle in different regions of Ethiopia (SER, SR, SWR and SSWR) but with the degradation of Ericsson performance 1 circle (SSWR) is reduced from Ericsson and given to Huawei, another 2 circles (Nekemte, Welega and Ambo areas) given to ZTE and the other circles (NR, NER, NWR, ER, Semera Region, Asosa Region, SSWR regions including Addis Ababa city) left for Huawei for this expansion project [6].

The Universal Mobile Telecommunication System (UMTS) network in Addis Ababa back in the year 2013 has its own limitations in terms of capacity, coverage and quality. To this end, the project aims to address the existing problems through complete swapping of the existing network elements along with a plan for additional capacity. Hence, the network planning will be done in such a way that the dimensioning part will start from scratch based on certain sets of requirements and the detailed planning will be done to maximize the capacity, coverage and service quality with minimum investment possible.

The advent of mobile communications such as GSM started its commercial operation in Addis Ababa city, Ethiopia in 2000. GSM system is very good at delivering voice services to its subscribers, and is the most common 2G system used all over the world. However, for data service, the situation is not the same. This has led to continuous network facility upgrade over existing GSM system in order to support more efficient data services.

1.2 Problem Statement

In recent years the government of Ethiopia made telecom infrastructures expansion projects throughout the country. Ethio-telecom is the only operator and responsible for every telecom services in Ethiopia. By this time the company has both fixed and radio access networks widely. One thing that has been clearly seen during the problem identification is that, the continuous demand on high data rate, multimedia services and increasing the number of subscribers here in Adama city is growing exponentially however; the service quality is far from being perfect.

The previously implemented generation of telecom network in our country has a coverage, capacity and radio propagation model selection for a certain terrain limitation in the existing network. The numbers of users are out growing the networks capacity. The quality of service demanded by the users is also growing beyond the capacity of the network to provide. So a proper radio propagation model selection for a certain terrain must be done before deploying the network.

The network operators may face huge losses resulting from complaints from the network users due to improper link budget calculations and path loss predictions. Thus, base station transmitters should be sited with through considerations on the effect of the location of other Base Stations on the signal strength, precise path loss calculations and using appropriate propagation models. An accurate estimation of path loss is useful for predicting coverage areas of base stations, frequency assignments, and proper determination of electric field strength, interference analysis, handover optimization, and power level adjustment.

As with the mentioned problems and future needs are the main initiation for this thesis by making a comparison between different radio propagation models, identify and evaluate the existing propagation model and find out the model that is best suitable in a particular terrain in Adama city for outdoor environments in UMTS networks. The comparison is made on the basis of path loss, antenna height and transmission frequency.

1.3 Objective of the Thesis

1.3.1 General Objective

- To evaluate the impact of selected propagation models aspects on performance of UMTS cellular network in Adama city, Ethiopia. The assessment is based on field measurements and simulations.

1.3.2 Specific Objective

Particularly, the thesis focuses on

- Understanding UMTS Radio frequency propagation models in detail.
- Carry out signal strength measurement survey via drive test in outdoor UMTS network propagation environment.
- Calculate path attenuation loss from the measured signal strength.
- Compare measured path loss values with some key existing path loss models such as; Okumura Path Loss Model, SUI Path Loss Model, COST 321 Hata Model, COST-231 Walfisch-Ikegami Model, Ericsson 9999 Model and Lee Path Loss model.
- Simulating those models with MATLAB software.

1.4 Literature Review

There have been several works done on the area of UMTS and LTE Radio frequency propagation models prediction and their performance evaluations on different network providers around the world. Some of the recently published articles related to this work are reviewed as follows:

"Performance Analysis and Comparison of Radio Frequency Propagation Models for Outdoor Environments in 4G LTE Network." This paper showed the dissertation concerns about the path loss calculation of Radio Frequency (RF) propagation models for 4G Long Term Evolution (LTE) Network to prefer the best Radio Frequency propagation model but not the real time model [10].

"On the Modeling of WCDMA System Performance with Propagation Data", *International Journal of Computer and Information Technology (ISBN 951-22-7063-3 and ISSN 1456-632X)*. This paper presents methods evaluating radio wave propagation, especially for cases where the base station antenna is below the rooftops, i.e. in the case of microcellular network environments. The developed microcellular propagation model has been developed for network planning purposes and it has been verified using numerous field propagation measurements. The model can be used in cases where the mobile station is located either indoors or outdoors [12].

"Comparative Analysis of Propagation Models in Urban Environments", *International Journal of Computer and Information Technology (ISSN: 2279 – 0764)*. The research includes field measurements and the choice of three propagation models with technological and environment of the test area. With a computer algorithm they select one of three outdoor propagation models for the study area; they compared results of field measurements versus selected models. The study was made in an environment with a high population density and a high demand of data traffic; they selected four Base Stations (Nodes B) in test area with the objective of observe real behavior of signal transmitted versus ideal behavior of an empirical method. In this paper the main drawback is that they used only the high populated areas (densely populated places) and it's difficult to conclude the chosen frequency propagation model is working for all areas like: suburban, rural, with some tree densities and the likes [13].

“Radio Field Strength Propagation Data and Path loss calculation Methods in UMTS Network”, *International Journal of Computer and Information Technology* (ISSN 2224-719X). They investigated the radio signal path attenuation behavior, by conducting an experimental measurement survey in a UMTS network transmitting at 2100MHz band in Government Reservation Area (GRA), Benin City [11].

“RF Propagation Measurement and Modeling to Support Adept Planning of Outdoor Wireless Local Area Networks in 2.4 GHz Band”, *American Journal of Engineering Research (AJER).* This paper presents a measurement based Log-distance propagation model for effective planning of outdoor WLAN in the 2.4 GHz Band. It presents a Log Distance Model for signal path loss prediction in WLAN and the model reveals that the channel path loss exponent and the mean pathloss intercept are 1.82 and 84 dB respectively. In summary, results show that the obstructions in the environment considered here had little effect (not much) on radio signals [14].

“Evaluation and Analysis of 3G Network in Lagos Metropolis, Nigeria”, *International Transaction of Electrical and Computer Engineers System, 2014, Vol. 2, No. 3.* They used two common path loss models COST 231 HATA and OKUMURA-HATA for the analysis and evaluation of the network. They considered the co-channel and adjacent-channel interference which may occur after the coverage is extended. They also recommended for the service providers as well as operators to correct the Up and down tilts of antennas should be made where necessary and changes of the azimuth of antennas should be done in other to avoid the direction of antenna facing to the road, so as to reduce the coverage radius [15].

“Comparison of Radio Wave Propagation Models for Mobile Networks”, *International Journal of Fuzzy Logic and Intelligent Systems.* This study reviewed radio wave propagation models based on BS and antenna characteristics. Each model is described separately, in terms of their characteristics, parameters, and areas of application. The ideal distances at which to use the current model are determined. The model considers the current structure of the BSs. The research shows how these models affect the performance of mobile networks in different scenarios [16].

“Comparative analysis of path loss prediction models for urban Macrocellular environments”, Nigerian *Journal of Technology*. In this paper three path loss prediction models namely free space, Hata and Egli were used to predict path losses. The calculated path loss values were compared with practical measured data obtained from a Visafone base station located in Uyo, Nigeria. The comparative analysis reveals that the mean square error (MSE) for free space, Hata and Egli were 16.24 dB, 2.37 dB and 8.40 dB respectively. The results showed that Hata’s model is the most accurate and reliable path loss prediction model for macro-cellular urban propagation environments, since its MSE value of 2.37 dB is smaller than the acceptable minimum MSE value of 6 dB for good signal propagation [17].

1.5 Methodology

The concept of radio frequency propagation models for UMTS network in outdoor environments leads to a smooth evolution to a 4G network and the introduction of intelligence towards the creation of smart infrastructures beyond the 2020, 5G wireless world, thus this thesis is entirely based on books on this area, different IEEE articles and journals, previous studies on this subject specifically on radio frequency propagation models of each radio access technologies.

1.5.1 Theoretical study

Standards and specification of UMTS network is developed through the cooperation of different countries. 3rd generation partnership project (3GPP) develops detail specifications and standards for the third generation network and beyond this standards are published through a series of releases starting from release 99. These releases are used as a reference both in the analysis and simulation of the network in this thesis.

There are a number of journals on the topic area of the thesis. These journals are studied to cover the challenges faced and solutions given by different scholars. These journals are used as a reference in the development of this thesis. In order to have a further understanding of the subject matter, books are used as a reference and to understand background concepts of the UMTS network. Some forums are used to get answers to problems which need further analysis of the expert who gives advices online.

1.5.2 Data collection

In the telecommunication system getting the correct and precise data is a must to do the analysis effectively. In this thesis we used different sources to collect this data. Ethio-telecom was a main source. They have given as not only the procedures to collect data but also design specification in the development of the network, the positions (longitude and latitude) of the Node B's, height of the towers, antenna position on the tower, antenna azimuth, transmission power of the antenna and in general the link budget of the network. And generally access to the infrastructure is granted by Ethio-telecom Adama branch and the project office.

Ericsson is the company which deployed UMTS network in the area selected and collected the data for the thesis work. So standards used by the company, books used to train the stuff and some manuals used for the deployment of the network are used as a source of data. Drive tests are conducted to measure different network and antenna parameters. Results from these tests are used in the thesis for the experimental and simulation result. In order to get the geographical data, online sites which provide a free access to a satellite images and terrain data are used as a source to get a digital terrain models. Software's like global mapper is used to analyze the data and convert it to the format which is compatible to the software used for the simulation purpose.

1.5.3 Simulation and experimental result

The method adopted for data collection in this thesis is drive test using the well-known software called Nemo Analyzer for data collection in field measurements and used Actix Analyzer for the analysis. The data collected were carefully and analyzed with Nemo and Actix Analyzer and MapInfo. The path loss that has been taken in filed measurements was analyzed with the use of MATLAB and proper suggestions and recommendations made for adequate optimization to be carried out in this area. Also the coverage area or the map of the test area should take with the Google Earth.

In these parts of the thesis work implementing the experimental data using MATLAB simulation software and the conclusion of those radio frequency propagation model scenarios and overall performance improvements will be analyzed based on the results.

1.6 Scope of the Thesis

This thesis work focuses on the essentials of radio frequency propagation model, path loss calculation and prediction of UMTS networks. It addresses in detail about the UMTS network architectures, radio frequency propagation model in outdoor environments for UMTS networks taking into account the actual morphology and topography details of Adama city for future deployment. It does not address the radio frequency propagation models in indoor environments of UMTS network, this is due to our country didn't start indoor antenna system.

And also the thesis didn't address for the coverage and capacity of UMTS network in Adama city because the topic by itself cover one research. In order to have a clear understanding of the behavior of the radio network, a number of experiments should be done on the propagation model. In this thesis work, a propagation model is adopted for the selected area and is used in the simulation software.

1.7 Thesis outline

This thesis report consists of five chapters. Chapter 1 introduces some background information, followed by statement of the problem, objectives of the thesis, some literature reviews relevant for this work, and the methodology**.** Chapter 2 deals with general overview of UMTS network technical information, architecture and features related to the radio frequency propagation models. Chapter 3 covers the wireless RF propagation models in detail. The different propagation models with their suitable applications according to the population and area are explained.

Chapter 4 starts with the RF propagation models for UMTS and explains the mathematical formulations for RF outdoor propagation models used in UMTS. This chapter describes radio frequency outdoor propagation models such as: The SUI path loss model, Ericson 9999 model, Okumura model, COST-231 Walfisch-Ikegami Model, Lee Path Loss model and Cost 231 Hata model.

Chapter 5 relates to the radio network coverage and drive test analysis tool. It explains the structure and functionalities of the software and discusses the prediction and performance results of the radio frequency propagation models for UMTS network. It shows the simulation results for path loss of different propagation models and the measured radio field strength data from the drive test for Path Loss prediction. And discuss the results from the field measurements and Path Loss calculation from those models. Chapter 6 concludes the thesis with summary of the entire thesis work and possibilities of future research for the recommendation of potential areas for future study are specified.

Chapter Two

2 UMTS Network Overview

2.1 Introduction

Mobile communication has experienced different generations and currently evolved into the fifth generation, which is ongoing with pre-commercialization. The 1G is the analog cellular mobile communication network in the time period from the middle of 1970s to the middle of 1980s [18]. The main feature of the 1G mobile communication systems is that they use the frequency reuse technology and adopt analog modulation for voice signals.

However, the limitations are:

- Low utilization of the frequency spectrum.
- Limited types of services.
- No high-speed data services.
- Poor confidentiality and high vulnerability to interception and number embezzlement.
- High equipment cost.
- Large volume and big weight.

The 3G mobile communication system is a kind of communication system that can provide multiple kinds of high quality multimedia services and they are compatible with the fixed networks. An increase in user demand have triggered researchers and industries to develop a new mobile communication system called fourth generation (4G) which can provide multiservice capacity by integrating all the mobile technologies aiming to have a common platform for all the technologies that have been developed so far. In 4G the functionality of the RNC and BSC is distributed to the e-node B and a set of servers and gateways, which makes it less expensive.

The fifth generation (5G) is expected to be, the future of mobile communication. Its radio access will be built upon both new Radio Access Technologies (RAT) and evolved existing wireless technologies like LTE, HSPA, GSM and Wi-Fi. To implement connectivity for a wide range of applications the capabilities of 5G wireless access must exceed far beyond previous generations. These capabilities include very high achievable data rates, very low latency and ultra-high reliability [13].

Below is comparison between different generations of mobile technologies in regard to standards, technology, Service type, multiplexing methods and switching methods.

Table 2-1: Comparison among different mobile technologies [19]

Technology	1G	2G,2.5G	3G	4G	5G
Start /Deployment	1970 /1984	1980 /1999	1990 /2002	2000 /2010	2010 /2020
Data rate	2kbps	14.4- 64kbps	2- 20Mbps	200Mbps- 1Gbps	1Gbps and higher
Standard	AMPS	CDMA,GSM, GPRS,EDGE	WCDMA, CDMA2000	Single unified standard	Single unified standard
Technology /feature	Analog	Digital	broad bandwidth CDMA,IP	Unified ip, LAN/WAN WLAN	Unified ip, LAN/WAN/ WLAN ,www
Service	voice	voice, SMS, higher capacity in packetized data	Integrated higher Quality audio, Video and data.	Dynamic information access wearable devices	Dynamic information Access wearable devices with all capabilities.
Switching	Circuit	Circuit, except core and data	packet except air interface	all packet	all packet
Core	PSTN	PSTN	packet	internet	internet
Handoff	Horizontal	Horizontal	Horizontal	Horizontal and Vertical	Horizontal and Vertical

Generally speaking, the 3G refer to those cellular mobile technologies which have been introduced after 2G systems such as GSM (Global system for mobile telecommunications), and which have several additional services related to high-speed data transport. 3G systems are expected to provide mobile multimedia services within similar quality, coverage and user cost constraints to those that exist today for implemented speech services, e.g. the GSM system.

The acronym for 3G systems in Europe is UMTS (Universal Mobile Telecommunications System), which has been standardized by the 3GPP (3rd Generation partnership project) organization. The respective international (in ITU, International Telecommunication Union) abbreviation for 3G is IMT-2000. UMTS utilizes WCDMA (Wideband Code Division Multiple Access) as radio access technology. This section describes the characteristics of the WCDMA system in general. The further evolution of the GSM system will enable some of the 3G services to be offered by an evolved GSM based radio system as well. The usage of GSM, GPRS (General packet radio system) and EDGE (Enhanced data rates for GSM evolution) for 3G services is studied later. Even though UMTS was meant to be a universal system, the different spectrum allocations for different parts of the world complicate its straightforward usage.

The 3G network will be able to transfer data for various kinds of services with considerably higher bit-rates than 2G systems. UMTS will be able to support both circuit switched and packet switched transmission modes.

In circuit switched traffic the connection between both ends is always open and data flows from one end to another at a constant rate and in real time, i.e. without any delays. Speech or video telephony is an example of these real time traffic applications.

In a packet switched connection, data is split into small portions (packets) and the data rate of each packet may not be constant. This means that there can be delays between the packets and this transport mode can therefore be referred to as non-real time. Examples of packet data applications are web browsing and downloading e-mail.

Typically, the transport layer protocol used for packet data services is either TCP (Transport control protocol) or UDP (User datagram protocol). Also, conversational or streaming services, such as speech, can be carried over non-real time connections, however this requires very tight delay requirements, and i.e. the delay between packets should not exceed a certain maximum value.

The success of internet protocol based technologies during the past few years will also be extended to mobile data communications by UMTS. With UMTS high-speed packet data services it will be possible to provide real time services such as voice and video that are based on packet data transport through radio access as well. Delay, bit-rate and data error rate requirements differ, however, among these services and thus, the radio bearer, which comprises the physical properties of the used transmission mode, depends on the requested service.

At the beginning of each (data) call the application will ask the network to establish a radio bearer with appropriate Quality of Service (QoS) requirements for the requested service and the network will subsequently check the available radio resources and will either reject or accept the request. The network is also able to change the bearer automatically, for example in handover situations where the mobile moves from one cell to another.

UMTS specifications include two different duplexing modes: FDD (Frequency division duplex) and TDD (Time division duplex). At the moment, deployment of the FDD mode is by far the more widespread as it is more suitable for fulfilling outdoor and large area coverage requirements. The usage of the UMTS TDD mode has been considered for indoor usage only. UMTS FDD mode will be considered in this thesis.

In WCDMA the information bits are spread over a wide bandwidth W by applying channel coding and by subsequently multiplying them with a spreading code. The bit rate of the code is 3.84 Mbit/s and the carrier bandwidth is nominally 5 MHz Each symbol in the WCDMA air interface contains a variable number of constant duration bits. The spreading factor, which is the ratio of the bit rate and the symbol rate across the air interface varies, hence different services with different bit rates can be obtained by changing the spreading factor.

The processing gain is defined as *10log10 (W/R)*, with *R* the user bit-rate. The processing gain includes both bandwidth enlarging effects, channel coding and spreading. For a speech user with a bit-rate of 12.2 kbps the processing gain is thus 25 dB, which means that in WCDMA the receiver base-band processing the received level of the desired signal will be increased by 25 dB relative to the thermal noise and interference.

On the other hand, in high bit-rate packet access the data bit rate and therefore the processing gain might change during the user session due to different service requirements, which means that the receiver's ability to extract the signal from interference changes as well. The total bit-rate that the system can support is therefore dependent on the current interference level. The data rate can be changed on a frame-to- frame basis. The duration of a WCDMA radio frame is 10 ms.

2.2 IMT2000 Frequency Band Allocation

In 1992, World Radio-communication Conference (WRC-92) allocated the frequency bands for the 3G mobile communication, with a total bandwidth of 230 MHz, as shown in Figure 2.1

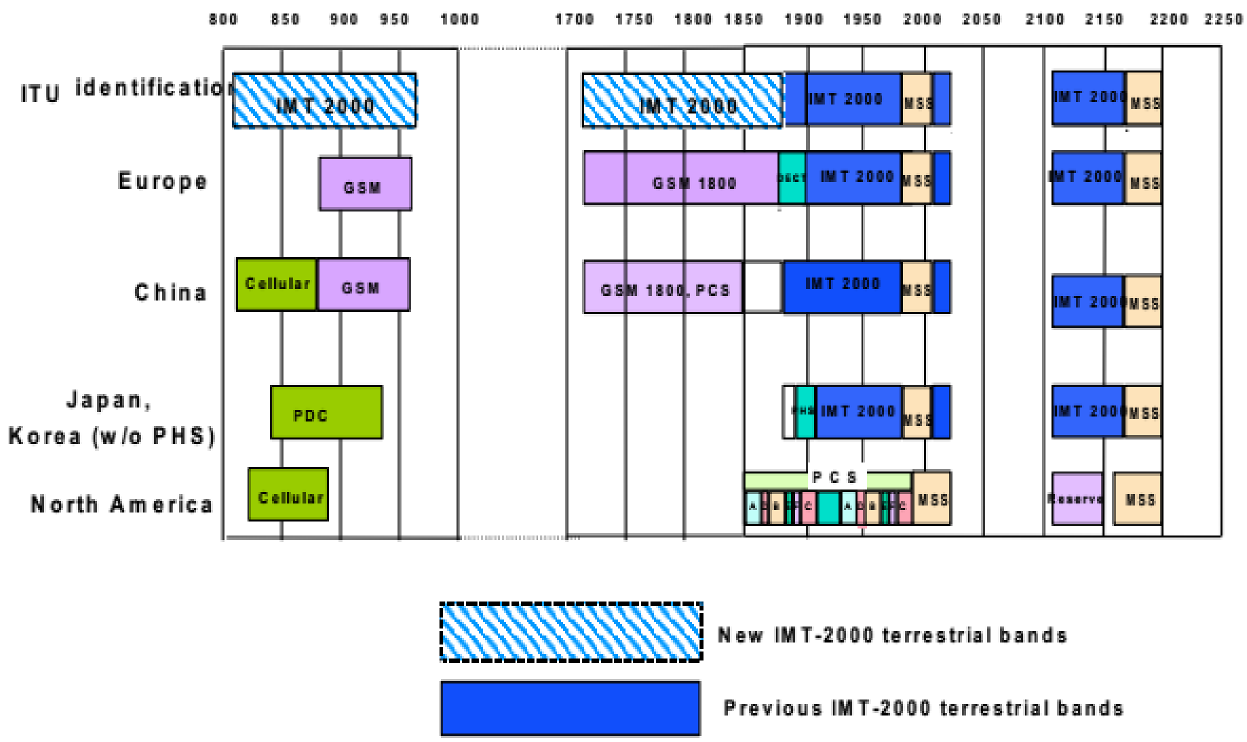


Figure 2-1: Frequency spectrum allocation [20]

At WRC92, ITU planned the symmetric frequency spectrum resources of 120MHz (1920MHz ~ 1980MHz, 2110MHz ~ 2170MHz) for use by the FDD, and asymmetric frequency spectrum resources of 35MHz (1900MHz ~ 1920MHz, 2010MHz ~ 2025MHz) for use by the TDD [14]. At WRC2000, the 800 MHz band (806MHz ~ 960MHz), 1.7GHz band (1710MHz ~ 1885MHz), and 2.5GHz band (2500MHz ~ 2690MHz) were added for use by the IMT- 2000 services [20]. These two combined make the future spectrum for 3G reach over 500 MHz, reserving enormous resource space for future applications.

2.3 Ethiopian Frequency Distribution

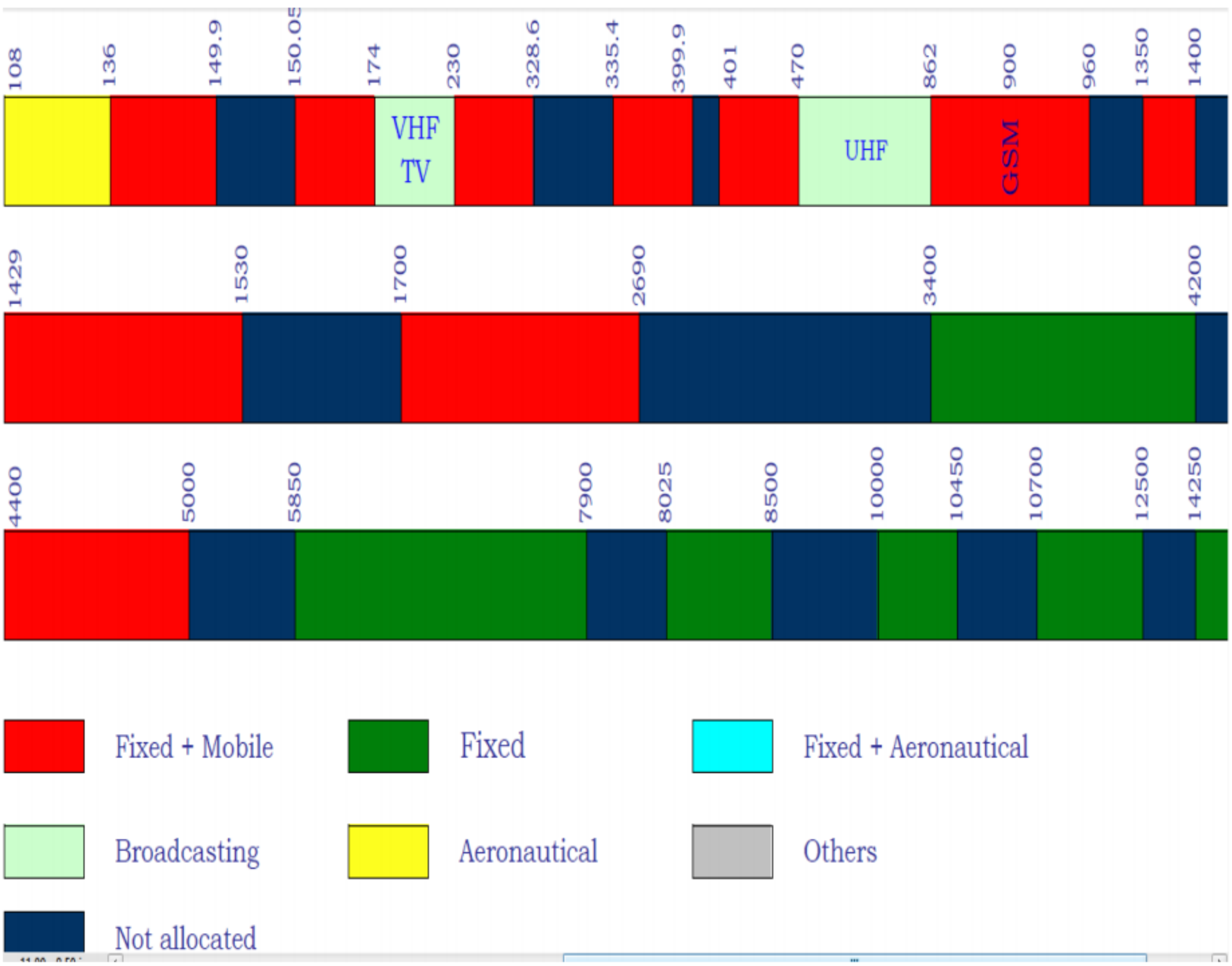


Figure 2-2: Sample Ethiopian frequency allocation [21]

3G Mobile network frequency range available in Ethiopia is from 1700 MHz to 2690 MHz of which 2140 MHz for downlink and 1950 MHz for uplink are used by Ethio-telecom UMTS radio network. As we can see from the above table the frequency range allocated for Ethio-telecom is a scarce resource, which we should bear it in mind in planning work. We may not be able to get the flexibility to use whatever frequency resource we need during the planning work and at the same time we have to consider also the interference we may face from neighboring frequency ranges.

2.4 WCDMA Services

Compatible with abundant services and applications of GSM and GPRS, the WCDMA system has an open integrated service platform to provide a wide prospect for various 3G service.

2.4.1 Categories of 3G Services

- Basic telecom services, including voice service, emergency call service and SMS.
- Supplementary services, the same as the supplementary services defined in GSM.
- Bearer services, including circuit bearer service and packet bearer service.
- Intelligent service, an intelligent network service based on CAMEL mechanism inherited from the GSM system.
- Location services, services related to location information, such as charging by area, mobile yellow page and emergency locating.
- Multimedia services, including circuit real-time multimedia service, packet real-time multimedia service and non-real-time store-and-transfer multimedia message service.

The above services are roughly classified. Actually these services may overlap. For example, charging by area is not only a location service, but also an intelligent service.

2.4.2 Features of 3G Services

3G (WCDMA) services are inherited from 2G (GSM) services. In a new architecture, new service capabilities are generated, and more service types are available. Service characteristics vary greatly, so each service features differently. Generally, there are features as follows:

- The real-time services such as voice service generally have the QoS requirement.
- Compatible backward with all the services provided by GSM.

- The concept of multimedia service is introduced.

2.5 UMTS System Structure

UMTS) is 3G mobile telecommunication systems by using the WCDMA air interface technology, usually called WCDMA telecommunication system. It adopts a structure similar to a 2G mobile telecommunication system, including the Radio Access Network (RAN) and the Core Network (CN) [22].

The RAN is used to process all the radio-related functions, while the CN is used to process all voice calls and data connections within the UMTS system, and implements the function of external network switching and routing. Logically, the CN is divided into the Circuit Switched (CS) Domain and the Packet Switched (PS) Domain. UMTS Terrestrial Radio Access Network (UTRAN), CN and User Equipment (UE) together constitute the whole UMTS system [22].

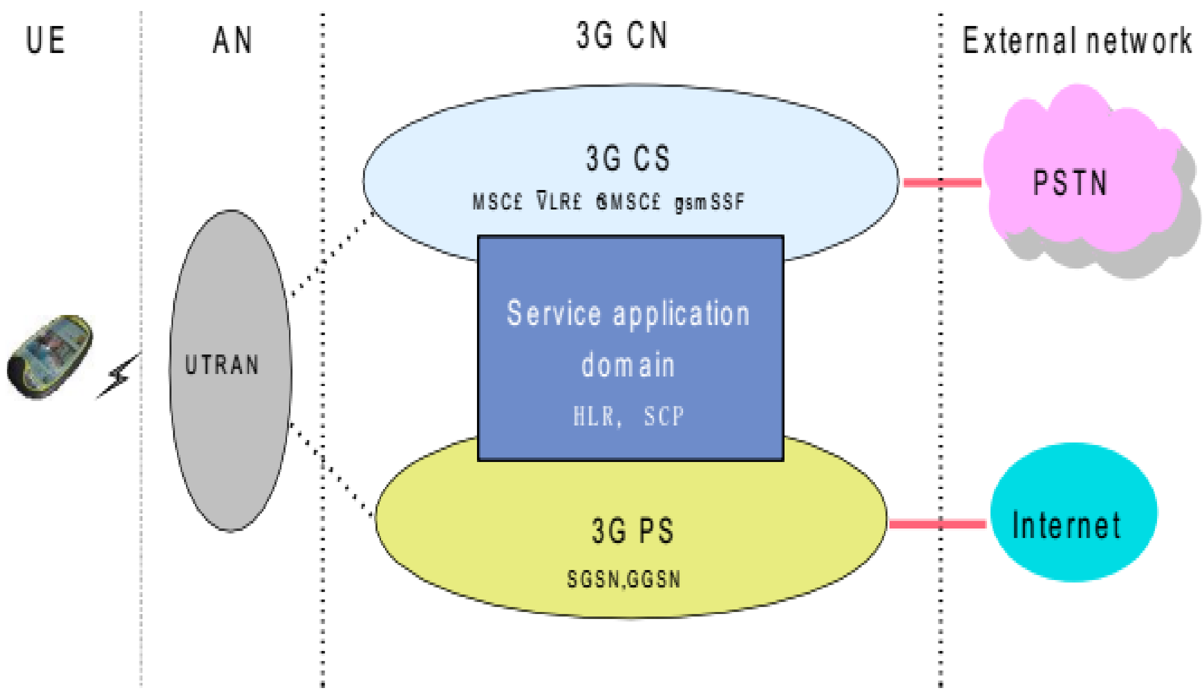


Figure 2-3: UMTS system structure [22]

2.6 UMTS Network System Composition

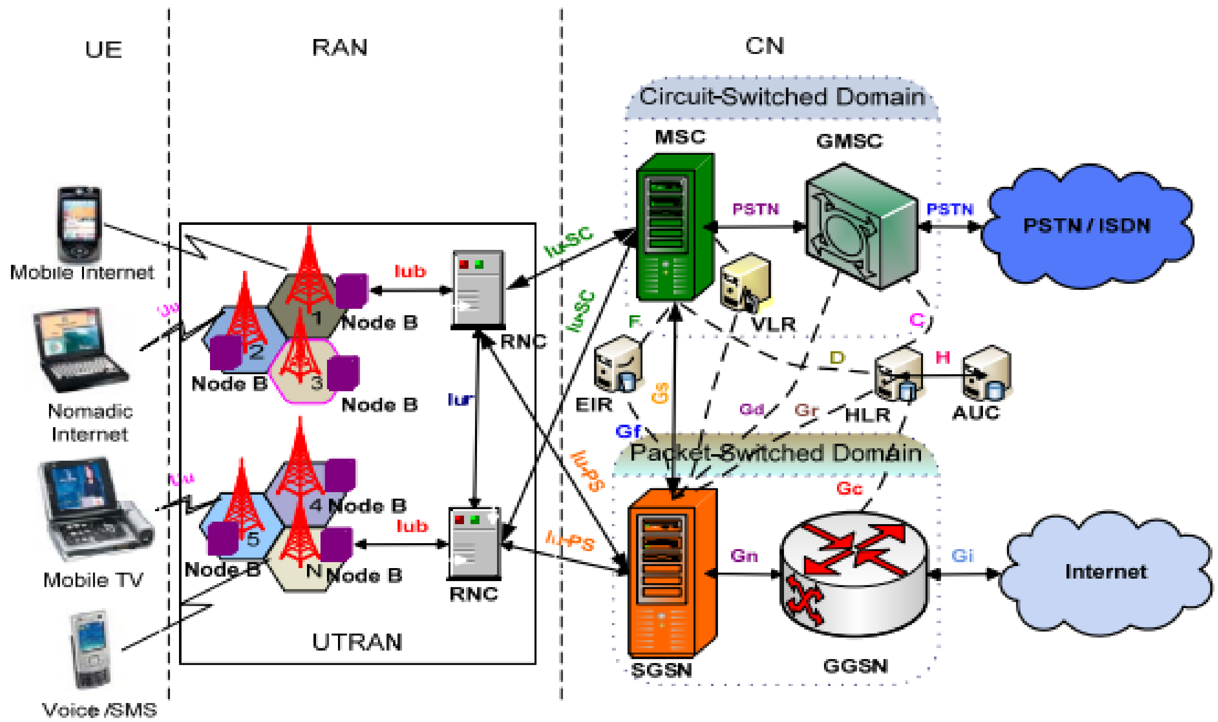


Figure 2-4: Composition of the UMTS network system [22]

The UMTS network system includes the following parts:

User Equipment (UE): The UE exchanges data with network equipment through the Uu interface, and provides services like common voice, data, mobile multi-media and Internet application (For example, E-mail, WWW browse and FTP). UE includes:

- Mobile Equipment (ME): Providing application and services.
- UMTS Subscriber Module (USIM): Providing subscriber identification.

UMTS Terrestrial Radio Access Network: Is divided into Node B and Radio Network Controller (RNC).

- **Node B: I**s the base station of the WCDMA system and processes the physical layer protocol of the Uu interface and interconnects with RNC via the standard Iub interface. Its main functions include spreading/de-spreading, modulation/demodulation, channel coding/decoding, and conversion between baseband signals and RF signals.

- **Radio Network Controller (RNC):** Responsible for connection establishment, call release and handover.

Core Network (CN): CN is responsible for connecting other networks as well as communicating and managing UEs. The core network equipment of different protocol versions in the WCDMA system is different. Generally, the R99 core network is divided into the CS domain and the PS domain [23]. The Release 4(R4) core network is the same as the Release 99 (R99) core network, but in the R4 core network, the MSC function of R99 CS is implemented by the two separate entities: Mobile Switching Center (MSC) Server and Media Gateway (MGW). The Release 5 (R5) core network is the same as the R4 core network except that R5 has been added with an IP multi-media domain [22]. Currently Ethio-telecom implemented Release 5 core network.

The **R99 core network** has the following functional entities:

Mobile Switching Center (MSC)/ Visitor Location Register (VLR): MSC/VLR is a functional node of the CS domain in the WCDMA core network. It connects with Universal Terrestrial Radio Access Network (UTRAN) via the Iu-CS interface, with external networks such as Public Switched Telephone Network (PSTN) and Integrated Service Digital Network (ISDN) via the PSTN/ISDN interface, with Home Location Register (HLR) via the C interface, with MSC/VLR, Gateway Mobile Switching Center (GMSC) or Short Message Center (SMC) via the E interface, with Serving GPRS Support Node (SGSN) via the Gs interface [24]. Its main functions are Call control, mobility management, authentication and ciphering of the CS domain.

Gateway Mobile Switching Center (GMSC): GMSC is the gateway node between the CS domain of the WCDMA mobile network and external networks, and it is an optional functional node. It connects with external networks (PSTN, ISDN and other PLMN) through the PSTN/ISDN interface, connects with HLR through the C interface [22]. It implements the routing function of incoming calls in the MSC function and internetwork settlement function of such external networks as fixed networks.

Serving GPRS Support Node (SGSN): Is a functional node of the PS domain in the WCDMA core network. It connects with UTRAN through the Iu-PS interface, with Gateway GPRS Support

Node (GGSN) through the Gn/Gp interface, with HLR/AUC through the Gr interface, with MSC/VLR through the Gs interface, with SMC through the Gd interface, with CG through the Ga interface and with SGSN interface through the Gn/Gp interface and its main functions are route forwarding, mobility management, authentication and ciphering of the PS domain.

Gateway GPRS Support Node (GGSN): is a functional node of the PS domain in the WCDMA core network. It connects with SGSN through the Gn/Gp interface and with external data networks (Internet/Intranet) through the Gi interface. It provides the routing and encapsulation of data packets between the WCDMA mobile network and the external data networks [18]. Its major functions are to provide interfaces to external IP packet networks. It needs to provide the gateway function for UE to access external packet networks. From the point of view of external networks, GGSN looks as if it were a router of all user IP networks in the addressable WCDMA mobile network and it needs to exchange routing information with external networks [22].

Home Location Register (HLR): is a functional node shared by the CS and PS domains in the WCDMA core network. It connects with MSC/VLR or GMSC through the C interface, with SGSN through the Gr interface, and with GGSN through the Gc interface. And its main functions are to store subscription information for subscribers, support new services and provide the enhanced authentication function [22].

The **Core Network** is a backbone network of telecommunication system that provides connections among different devices. The basic 3G CN architecture is based on GSM network with GPRS. The main functions of the CN are to provide switching, routing and transit for user traffic. The 3G Core Network is divided into two domains: **circuit switched** and **packet switched** domains.

The **circuit switched domain** elements are:

Mobile Switching Center (MSC): A Mobile Switching Center is a telecommunication switch or exchange within a cellular network architecture which is capable of interworking with location data bases. The main task of MSC is to route, switch and transmit the circuit switched data received from Radio Network Controller (RNC) to the PSTN / ISDN networks via GMSC and vice versa. MSC is the core element of GSM network.

Visitor Location Register (VLR): The Visitor Location Register is a network database which keeps the information about all the roaming mobile customers required for call handling and mobility management. Whenever an MSC detects a new mobile subscriber, in addition to creating a new record in the VLR, it also updates the HLR (Home Location Register) of the mobile subscriber.

Gateway MSC (GMSC): The Gateway MSC is the main routing element for the circuit switched data from the UMTS network to the PSTN/ ISDN network or vice-versa. A GMSC is the MSC that determines which visited MSC the subscriber who is being called currently located. All mobile-to-mobile calls and PSTN to Mobile calls are routed through GMSC. It terminates the PSTN signaling and traffic formats and converts this to protocols employed in mobile networks. For mobile terminated calls, it interacts with HLR to obtain routing information.

The **packet switched domain** elements are:

Serving GPRS Support Node (SGSN): A Serving GPRS Support Node (SGSN) is responsible for the delivery of packet switched data received from Radio Network Controller (RNC) to the Gateway GPRS Support Node or vice-versa. Its main tasks include packet routing and transfer, mobility management, logical link management.

Gateway GPRS Support Node (GGSN): Like GMSC is the main routing element for circuit switched data to the PSTN or ISDN network, GGSN is the main routing element for the packet switched data of UMTS network to the Ethernet network.

Besides the **circuit switched** and the **packet switched** elements, the shared elements of both the domains are:

Equipment Identity Register (EIR): The Equipment Identity Register is a database that keeps a list of mobile phones (identified by their IMEI), which are to be banned from the network or monitored. When a mobile requests services from the network, its IMEI (International Mobile Equipment Identity) is checked against the EIR and then decides whether to allow the service or banned.

Home Location Register (HLR): The Home Location Register is a central database that contains information of each mobile phone subscriber that is authorized to use the network. More precisely, the HLR stores the information of every SIM card issued by the mobile phone operator. It is responsible for the maintenance or user subscription information.

Authentication Center (AUC): The function of AUC is to authenticate each SIM card that attempts to connect the GSM network. Once the authentication is successful, the HLR is allowed to manage the SIM and services.

2.6.1 Basic Structure of UMTS Terrestrial Radio Access Network (UTRAN)

UTRAN includes one or several Radio Network Subsystems (RNS).A RNS is composed of one RNC and one or several node B's. The Iu interface is used between RNC and CN while the Iub is adopted between RNC and node B, Within UTRAN RNCs connect with one another through the Iur interface [25]. The Iur interface can connect RNCs via the direct physical connections among them or connect them through the transport network. RNC is used to allocate and control the radio resources of the connected node B, however, node B serves to convert the data flows between the Iub interface and the Uu interface and, at the same time it also participated in part of radio resource management [18].

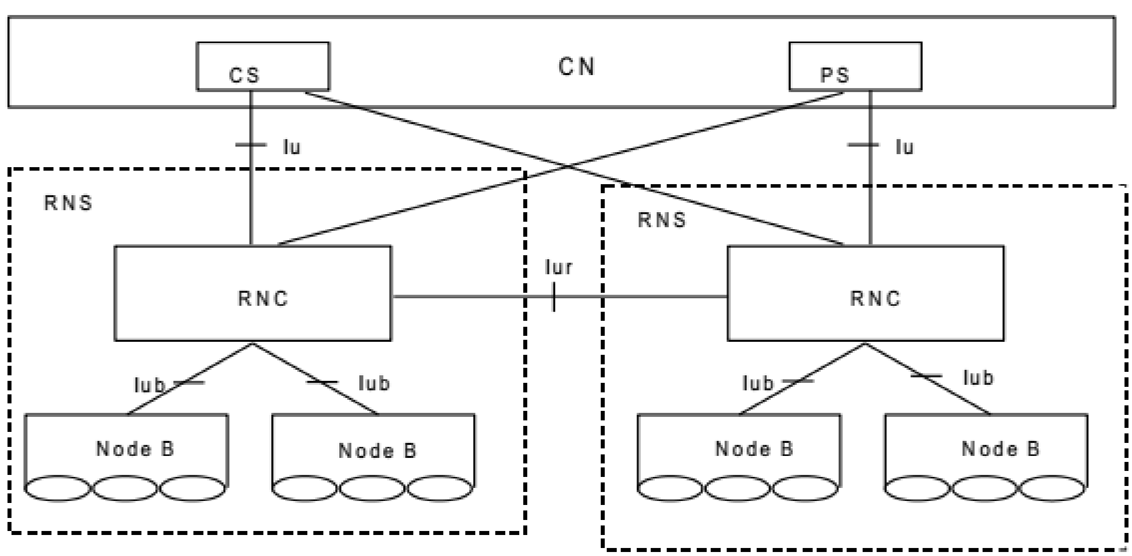


Figure 2-5: UTRAN structure [22]

UTRAN has the following main interfaces:

Cu interface: The Cu interface is the electrical interface between the USIM card and ME, and it adopts the standard interface.

Uu interface: The Uu interface is the radio interface of WCDMA. UE accesses the UMTS system through the Uu interface, so we can say the Uu interface is the most important open interface in the UMTS system.

Iur interface: The Iur interface is the interface connecting RNCs. It is specific to the UMTS system for mobility management of UEs in RAN. For example, when different RNCs perform soft handover, all UE data are transmitted from the working RNC to the candidate RNC through the open standard Iur interface.

Iub interface: The Iub interface is an open standard interface connecting Node B and RNC. It allows RNC to connect to Node B from another equipment manufacturer.

Iu interface: The Iu interface is the interface between UTRAN and CN. Similar to the A interface and the Gb interface in the GSM system, it is also an open standard interface. It allows different vendor's UTRAN and CN to connect together, and can be divided into the Iu-CS interface and the Iu-PS interface.

2.6.2 Basic Protocol Structure of UTRAN Interfaces

The principle of this universal protocol model design is that logically the layer and the plane should be independent; if necessary you can modify a part of the protocol structure without modifying other parts, this feature provides us the capability to made changes in a single module without affecting others.

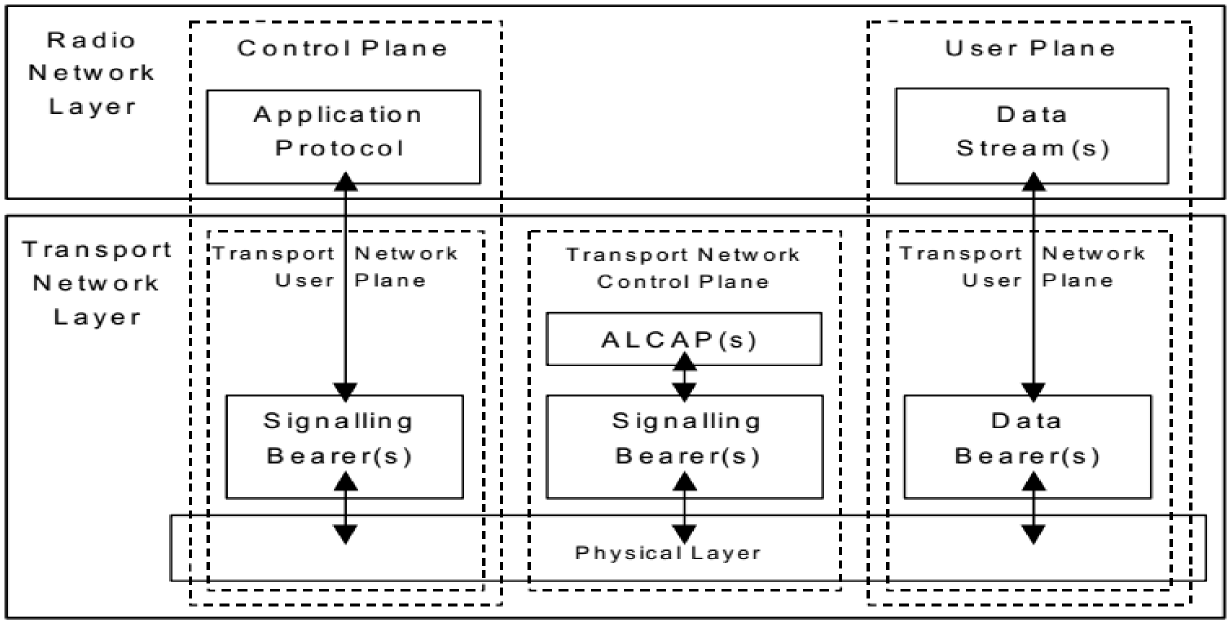


Figure 2-6 : Universal protocol model of UTRAN interfaces [19]

Horizontally, the protocol structure contains the radio network layer and the transport network layer. All protocols related to UTRAN are contained in the radio network layer. The transport network layer is the standard transmission technique adopted by UTRAN, and it has nothing to do with the specific functions of UTRAN [22].

In conclusion, UTRAN obeys the following principles. The signaling plane is separated from the data plane. UTRAN/CN functions are separated from the transport layer that is the radio network layer doesn't depend on the specific transmission technique. Besides Macro diversity (FDD Only) is processed totally by UTRAN and the mobility management of Radio Resource Control (RRC) connections.

2.7 UMTS Radio Interface Technology

In the WCDMA system, the mobile UE connects with the system network through a radio channel on the radio interface, called Uu interface, this interface is one of the most important interfaces in the WCDMA system [20]. The radio interface technology is the core one in the WCDMA system, which shows the core technologies and main differences of all kinds of 3G mobile communication systems.

2.7.1 Protocol Structure of Radio Interfaces

From the perspective of protocol structure, the WCDMA radio interface is composed of the following three layers: Physical layer, medium access control layer and RRC layer [20]. In terms of protocol layer, the WCDMA radio interface has three channels: Physical channel, transport channel and logical channel.

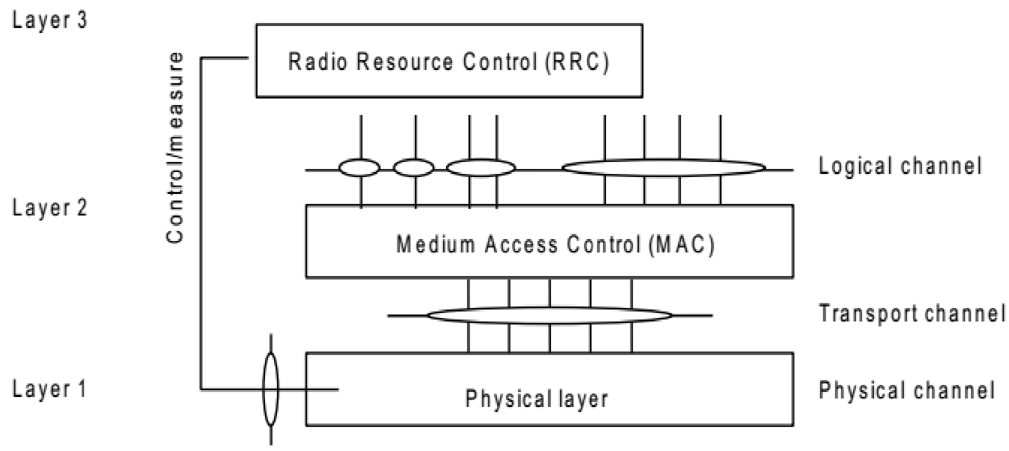


Figure 2-7: Physical structure of radio interface [26]

The circles among different layers/sub-layers in the Figure are Service Access Points (SAPs).The physical layer provides data transmission services required by the upper layer. These services are accessed by using the transport channel through MAC sub layer.

The physical layer provides services for the Medium Access Control (MAC) layer through a transport channel, while the proprieties of transmission data determine what kind of transport channel should be used and how to transmit [25]. The MAC layer provides the RRC layer with services through a logical channel, while the proprieties of the transmitted data determine the type of the logical channel. In the MAC layer, the logical channel is mapped as a transport channel. MAC layer should select proper Transport Format (TF) for each transport channel, according to the transient source rate of logical channels.

The RRC layer configures protocol entities of lower layers as physical channels, transport channels and logical channels by using the control interfaces between it and lower layer protocols.

Logical channel: Carrying user services directly. According to the types of the carried services, it falls into two types: Control channel (for signaling and communication among different network elements) and service channel (used for transporting user traffic).

Transport channel: It is the interface of radio interface layer 2 and physical layer, and is the service provided for MAC layer by the physical layer. According to whether the information transported is dedicated information for a user or common information for all users, it is divided into dedicated channel and common channel.

Physical channel: It is the ultimate embodiment of all kinds of information when they are transmitted on radio interfaces. Each kind of channel which uses dedicated carrier frequency, code (spreading code and scramble) and carrier phase (I or Q) can be regarded as a dedicated channel [25]. At the transmitting end, the data flows from MAC and upper layers are transmitted in radio interfaces, reused and mapped by channel coding, transport channel and physical channel, spread and modulated by physical channel, and then formed the data flows of radio interfaces to be transported on the radio interfaces. At the receiver side the reverse process will be applied.

2.7.2 Spreading Spectrum and Scrambling

On radio interfaces, after source coding and channel coding, the data flow continues to spread spectrum, scramble and modulate.

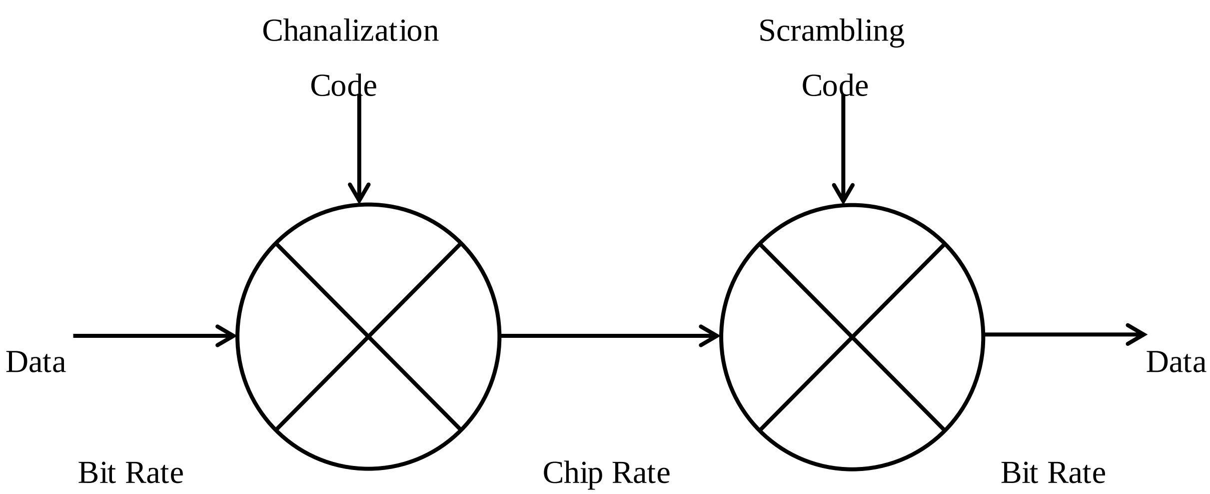


Figure 2-8: Relation between spreading spectrum and scrambling code [26]

The code word used for spreading spectrum is called channelization code, for which Orthogonal Variable Spreading Factor (OVSF) code is used. The code word used for scrambling is called scramble, which adopts Gold sequence.

Spreading spectrum and channelization code

Channelization code is used to distinguish the transmission from the same source, that is, different physical channels of the same terminal between the downlink and uplink connection of a sector. The spread spectrum/channelization of UTRAN is based on OVSF technology.

OVSF can change the spreading factor and keep the orthogonally among different spreading codes with different lengths. If one connection uses variable spreading factors just select the channelization codes from the branch of the code tree directed by the minimum spreading factor code.

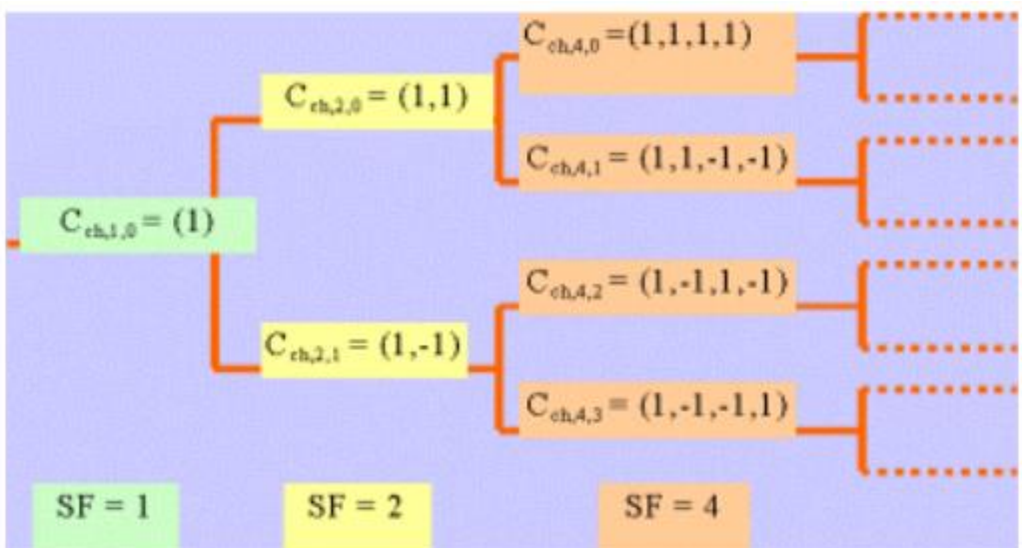


Figure 2-9: Structure of channelization code tree [26]

Scramble

Scramble is used to separate the terminals or BSs, and it is used after spreading spectrum, so it does not change the bandwidth of signals but only separate the signals from different sources. After scrambling, the problem that several transmitters use the same code word spreading spectrum is solved.

2.7.3 Logical Channel

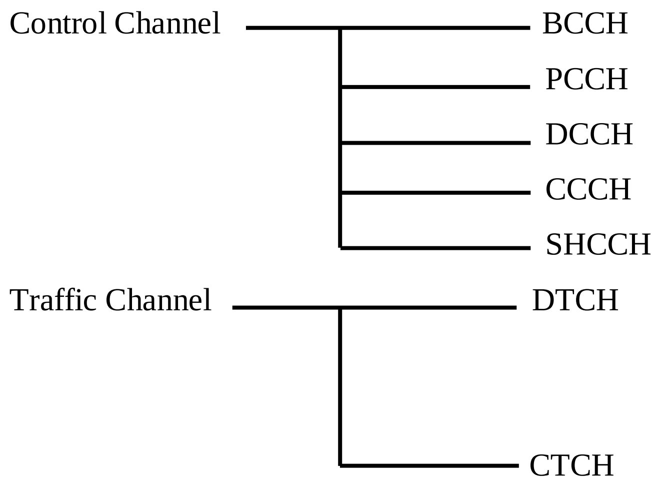


Figure 2-10: Types of logical channels [26]

Control channel: The following control channels are only used to transmit the information of control plane.

- Broadcast Control Channel (BCCH): Downlink channel used to broadcast system messages.
- Paging Control Channel (PCCH): Downlink channel used to send paging messages.
- Common Control Channel (CCCH): Bidirectional channel used to send control messages between the network and UE.
- Dedicated Control Channel (DCCH): it is a Bidirectional channel, which will be used to send and receive control messages between the network and UE.

Traffic channel: The following traffic channels are only used to transmit the information of user plane.

- Dedicated Traffic Channel (DTCH): Bidirectional point-to-point channel dedicated for one UE and used to transport user information [20].
- Common Traffic Channel (CTCH): it is a Point-to-point down link channel which is used to transport the dedicated subscriber information for all or a group of UEs.

2.7.4 Transport Channel

Types of Transport Channels

A transport channel is used at the physical layer to provide services for the upper layer. It defines the mode and features of data transmission on air interfaces. It is divided into two types: Dedicated channel and common channel. The main difference between them is: Resources in the common channel are shared by all users or a group of users within a neighborhood, while resources in the dedicated channel are defined by the dedicated code on specific frequency, and they are used only for individual users.

The figure in [2-11] shows the different transport channel types and their work flow direction as unilateral (single line) and bilateral direction (double line) [26].

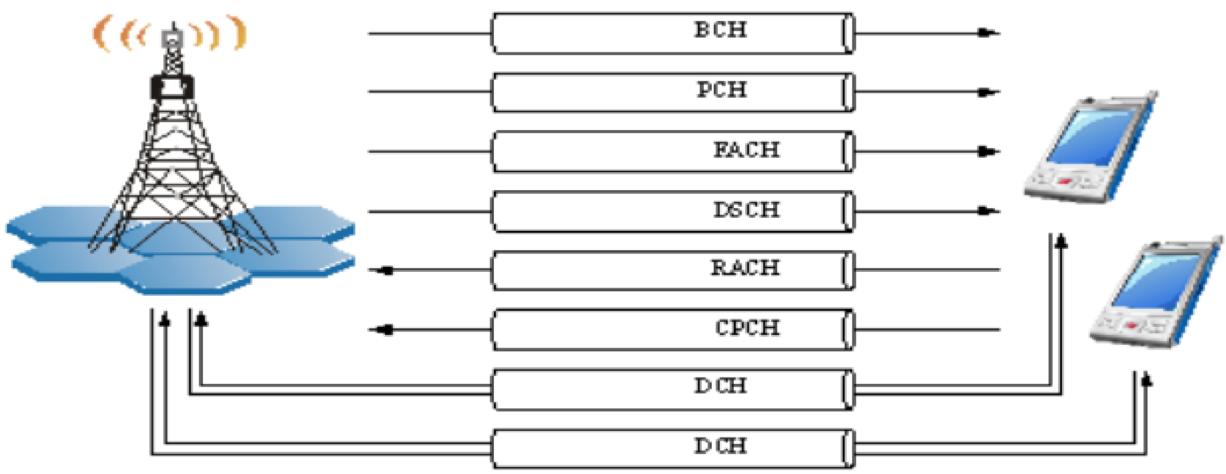


Figure 2-11: Transport channels [27]

Dedicated Transport Channel

Only one kind of dedicated transport channel exists, that is, Dedicated Channel (DCH). The Dedicated Channel (DCH) is an uplink or downlink channel. In the whole or part of the neighborhood, DCH uses beam-forming antenna to transmit.

Common Transport Channel

Totally, there are the following six transport channels:

- Random Access Channel (RACH): it is an uplink transport channel. It always receives information in the whole cell.

- Broadcast Channel (BCH): The Broadcast Channel (BCH) is a downlink transport channel that is used to broadcast system- and cell-specific information. The BCH is always transmitted over the entire cell and has a single transport format.
- Forward Access Channel (FACH): The Forward Access Channel (FACH) is a downlink transport channel. The FACH is transmitted over the entire cell. It is used to transmit control information after Base station has received the random access requirement sent by UE. FACH is also can be used to send packet data.

There is one or several FACH within one cell. One of them must has low data rate so all terminals in this cell can receive it. The others can have high data rate.

- Paging Channel (PCH): The Paging Channel (PCH) is a downlink transport channel. The PCH is always transmitted over the entire cell.
- Common Packet Channel (CPCH): it is an uplink transport channel which is associated with the dedicated channel of a downlink. This dedicated channel is used to provide CPCH power control of the uplink and CPCH control commands [28].
- Downlink Shared Channel (DSCH): it is a downlink transport channel shared by some UEs, associating with one or more DCHs. In the whole or part of the cell, DSCH uses beam-forming antenna to transmit.

Mapping from the Logical Channel to the Transport Channel

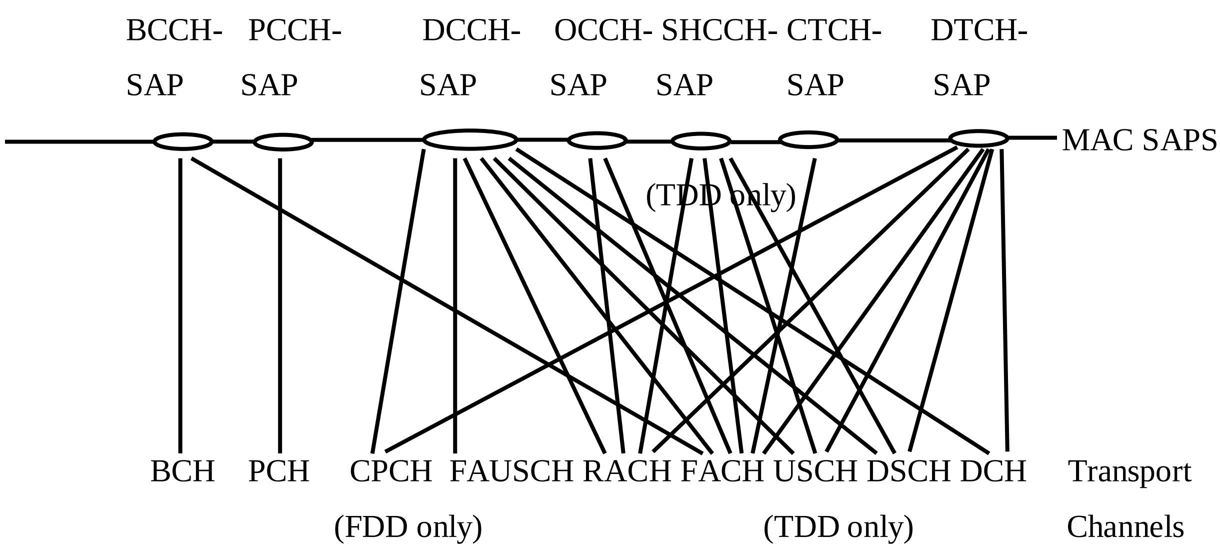


Figure 2-12: Mapping between the logical channel and the transport channel [28]

In addition to the transport channels introduced earlier, there exist physical channels to carry only information relevant to physical layer procedures. The Synchronization Channel (SCH), the Common Pilot Channel (CPICH) and the Acquisition Indication Channel (AICH) are not directly visible to higher layers and are mandatory from the system function point of view, to be transmitted from every base station. The CPCH Status Indication Channel (CSICH) and the Collision Detection/Channel Assignment Indication Channel (CD/CA-ICH) are needed if CPCH is used [27].

2.8 Fundamentals of the UMTS Technology

2.8.1 Channel Coding/Decoding

A radio channel is an adverse transmission channel. When digital signals transmitted over a radio channel, bit errors may occur in the transmission data flow due to various reasons, causing image jumps and disconnection at the receive end. The step of channel coding can be used to process the data flow appropriately, so that the system can have error correction capability and anti-interference capability to certain extent, thus greatly avoiding bit errors in the code flow. Therefore, channel coding aims at increasing data transmission efficiency by reducing bit error rate [23].

Ultimately, channel coding intends to increase the reliability of the channel, but it may reduce the transmission of useful information data. Channel coding works by inserting some code elements, usually referred to as overhead, into the source data code flow, for error detection and correction at the receiving end. This is like the transport of glasses. To ensure that no glasses are broken during this process, we usually use foams or sponge to package them. However, such packaging reduces the total number of glasses. Similarly, over a channel with fixed bandwidth, the total transmission code rate is fixed. As channel coding increases data amount, the useful information code rate is reduced [28].

2.8.2 Spread Spectrum

Spread Spectrum is an information transmission mode. It modulates information signals with spreading code at sending end and enables spectrum width of information signals much wider than bandwidth for information transmission. It dispreads at receiving end with same spreading code, to resume data of transmitted information [29].

WCDMA allows many subscribers to use the same frequency at the same time. In order to distinguish between the users, the information undergoes a process known as spreading that is, the information is multiplied by a channelization and scrambling code, hence WCDMA is referred to as a spread spectrum technology.

In WCDMA each user is assigned a unique code, which it uses to encode its information-bearing signal. The receiver, knowing the code sequences of the user, decodes a received signal after reception and recovers the original data. Spreading codes are divided into scrambling codes and channelization codes (CC). Each transmitter (cell in downlink) is assigned a different scrambling code and each data channel is assigned different CC code.

Spreading codes are also known as spreading sequences. There are two types of spreading codes in the UTRAN air interface: orthogonal codes and pseudorandom codes. Pseudorandom codes are also known as pseudo noise (PN) codes. Both kinds of codes are used together in the uplink and in the downlink. The same code is always used for both the spreading and dispreading of a signal. This is possible because the spreading process is actually an XOR operation with the data stream and the spreading code [31].

2.8.3 Modulation and Demodulation

Modulation is the process to use one signal (known as modulation signal) to control another signal of carrier (known as carrier signal), so that a characteristic parameter of the later changes with the former. At the receiving end, the process to restore the original signal from the modulated signal is called demodulation.

During signal modulation, a high-frequency sine signal is often used as the carrier signal. One sine signal involves three parameters: amplitude, frequency and phase. Modulation of each of these three parameters is respectively called amplitude modulation, frequency modulation, and phase modulation [25].

2.9 UMTS Advancements to HSPA+

2.9.1 WCDMA and HSPA evolution

Table 2-2: Summary of different releases [19]

Version	Released	Info Related to 3G and LTE
Release 99	2000 Q1	First UMTS 3G networks, incorporating a CDMA air interface
Release 4	2000 Q2	Originally called the Release 2000 - added features including an all-IP Core Network
Release 5	2002 Q1	Introduced IMS and HSDPA
Release 6	2004 Q4	Adds HSUPA, MBMS, enhancements to IMS.
Release 7	2007 Q4	This specification also focuses on HSPA+ (High Speed Packet Access Evolution).
Release 8	2008 Q4	First LTE release. All-IP Network (SAE). Dual-Cell HSDPA.
Release 9	2009 Q4	WiMAX and LTE/UMTS Interoperability. Dual-Cell HSDPA with MIMO, Dual-Cell HSUPA. LTE HeNB.
Release 10	2011 Q1	Backwards compatible with release 8 (LTE). Multi-Cell HSDPA (4 carriers).
Release 11	2012 Q3	Advanced IP Interconnection of Services.
Release 12	March 2015	Enhanced Small Cells, Carrier Aggregation, MIMO (3D channel modeling, elevation beam forming, massive MIMO), New and Enhanced
Release 13	March 2016	LTE in unlicensed, LTE enhancements for Machine-Type Communication. Elevation beam forming / Full-Dimension MIMO, Indoor positioning

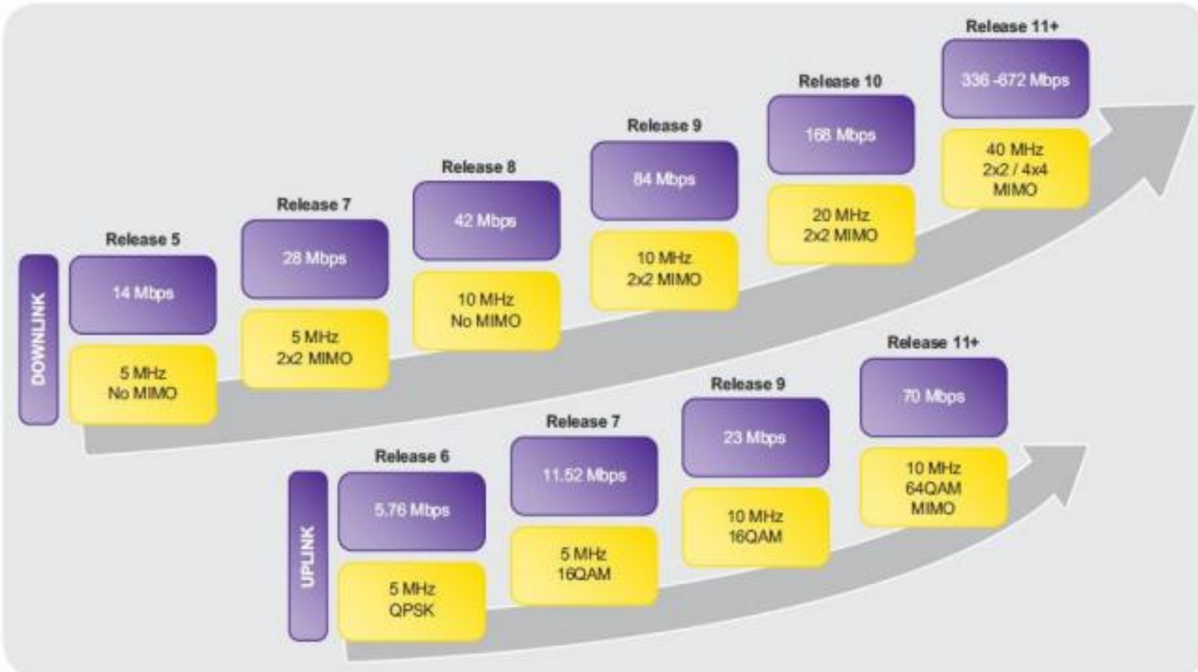


Figure 2-13: WCDMA Evolutions to HSPA+ [19]

Figure [2-13] shows the different evolutionary releases of WCDMA and their corresponding capability and change compare to their previous versions.

2.10 UMTS Operation Modes and Multiple Accesses

UMTS may work in two different modes, the TDD and the FDD ones [3GPP00e] [3GPP00f], which means that channels in the UL and DL will be managed in two different ways:

In the FDD mode, two pairs of frequency bands are used at the same time, one for UL and the other for DL. This mode uses Wideband Code Division Multiple Access (WCDMA), the carried services being characterized by their symmetric traffic, like voice. This mode will be the most used, being deployed in every kind of environment, particularly in macro and micro cells.

In the TDD mode, both UL and DL use the same frequency, through a scheme of time division - code division multiple access (TD-CDMA) in unpaired bands, which will be advantageous to handle services with asymmetric traffic, like Internet one. It will be used mainly in Pico-cells (indoor) or in hot-spot areas.

The wide bandwidth of WCDMA gives an inherent performance gain over previous cellular systems, since it reduces the fading of the radio signal. In addition, WCDMA uses coherent demodulation in UL, a feature that was not previously implemented in cellular CDMA systems.

WCDMA use BPSK (Binary phase-shift keying) and QPSK (Quadrature phase-shift keying) for data modulations in uplink and downlink respectively [20].

2.11 Radio Resource Management in WCDMA

The performance of the radio system is governed by the system parameters (minimum requirements usually defined in system specifications), radio network planning as well as the RRM algorithms and parameterization. The RRM functionalities are responsible for allocating radio resources (such as RF power, time, codes and radio carrier frequencies) for each user so that the QoS targets for each user are met. Some parameters that affect a WCDMA network performance are:

2.11.1 Power Control

Efficient power control is very important for WCDMA network performance. It is needed to minimize the interference in the system, and given the nature of the DS-CDMA (all signals are transmitted using the same frequency at the same time), a good power control algorithm is essential. Power control is needed both in the uplink and in the downlink, although for different reasons. In the uplink direction, all signals should arrive at the base station’s receiver with the same signal power.

Signals that are mutually orthogonal do not interfere with each other, possible power level, which maintains the required signal quality. A mobile station close to the base station would not suffer if the signals it receives have been sent using too much power. But other users, especially those in other cells, could receive this signal as non-orthogonal noise, and therefore unnecessary high power levels should be avoided [32].

The WCDMA radio link between the MS and the RAN is designed so as to maintain a constant quality which can be defined for example by the frame error rate (FER). Constant quality is justified by the fact that if the link quality were to be too high (the FER is below its target value) the link specific power allocated for one user would be higher than necessary. This causes additional interference to other users of the network, which in turn decreases the overall network capacity. The constant quality in the uplink and in the downlink is ensured by an outer power control (PC) loop.

In the uplink direction (from the MS to the BS) the RNC asks the BS to decrease the SIR (Signal-to-Interference Ratio) target in case the measured quality (FER) is above the FER target and increase the SIR target if the measured quality (FER) is below the FER target. In the closed PC loop the BS asks the MS to change its transmitting power based on the SIR measurements. The measured SIR is compared periodically to the SIR-target sent by the RNC.

In the downlink direction (BS to MS), the MS measures the SIR, compares it with the target SIR set by the downlink outer loop PC, and asks the BS to increase or decrease the power dedicated to that particular mobile accordingly. On the other hand, fast power adaptation in response to changes in the own (MS to BS) link causes power peaks in transmission which disturbs adjacent cells in uplink direction.

2.11.2 Handovers

In order to allow high mobility for the user the system enables several types of handovers (HO). The MS can make the HO from one cell/sector to another (soft/softer HO), from one frequency to another (inter-frequency HO) and from one system to another (inter-system HO). In addition to this, the mobile is able to make intra-frequency HO (hard HO).

To initiate soft handover, the mobile selects the preferred cells (active set) based on its common pilot power measurements or more specifically the wideband SIR measurements from the pilot channel and the BS either accepts or rejects the suggested cell selection. The mobile can be connected to one or more base stations (soft handover) or one or more base station sectors (softer handover) at the same time.

The most likely interfering mobiles are typically at the cell border (i.e. those using the highest Tx (transmit powers) and during soft(er) HO they are power controlled by two (or more) adjacent base stations. The soft(er) HO provides also a seamless handover across the cell borders. On the other hand, soft(er) handover consumes base station processing and RF transmission power resources and also increases the need for signaling between the base station and RNC.

2.11.3 Other Radio Resource Control Algorithms

In the WCDMA system each user induces interference to other users. In order to achieve the predefined targets for the performance (i.e. coverage, capacity, QoS) and to keep the MS and BS transmit powers stable at all times, the interference levels throughout the system have to be managed in a controlled way. Hence, in addition to the above mentioned handover and power control, there are other RRM functionalities in the system managing the multiple access interference (MAI): **the admission control (AC), the load control (LC)** and **the packet scheduling (PS)** functionalities, which are located in the RNC and/or in the BS.

The A**dmission Control (AC):** either accepts or rejects the establishment of a new radio bearer. This is subject to the constraint of keeping the coverage and the capacity of the RAN at a planned target. The AC estimates the total interference levels if a user requesting the service is to be allowed to enter the system. If the total interference levels are above the predefined target values, the request is denied.

The **Packet Scheduling (PS):** controls the bit-rates and the load of the non-real-time traffic. The packet scheduler estimates the acceptable bit-rates and loading for an additionally requested packet data service and also controls the total load by changing bit-rates or dropping bearers. The PS schedules also transmit periods for the packet data usage.

The **load control (LC)**: only takes place when, for some reason, the admission control or the packet scheduler cannot control the load and the system has been driven into an overload situation. In this case the LC asks the users to decrease the target SIR or it reduces the data throughput or, in extreme cases, drops the calls.

2.12 Interference in WCDMA

The air interface capacity of a WCDMA cell is not pre-determined from the available spectrum amount and thus it cannot be planned very accurately. That is, the capacity is dependent on the performance of the receivers in a time varying environment and also on the interference within its own network and the spectrally adjacent network. The capacity might also be limited by the maximum available number of spreading codes and hardware resources.

One of the most challenging parts of radio network planning is the estimation of the required traffic since the radio network planner has to know, at least approximately, what kind of services are going to be used, the likely user locations and hot-spot areas. In most cases the WCDMA network is interference limited and thus the radio network planning can be considered as being the control of the interference throughout the system. When the number of users (or user bit-rates) increases the interference increases, meanwhile the required MS and BS transmission powers have to increase, in order to achieve a required performance. For both uplink and downlink the interference present at the receivers also varies in time.

The interference sources can be grouped as follows:

1) Inter symbol interference (ISI). This interference is due to overlapping symbols in the same bit-stream caused by multipath radio propagation.
2) Own cell interference caused by other users connected to the same cell.
3) Other cell interference caused by users connected to other cells in the same system.
4) Power leakage from the adjacent carrier in the same system. This includes intra operator interference and inters operator interference.
5) Interference from other systems (such as GSM, WCDMA TDD, CDMA2000, etc)
6) Interference from other, non-controllable sources such as traffic, illegal transmissions, radar systems, electronic devices, etc.

By learning the system structure, interface technology, it evolution and advancements, protocol structure and the process of physical channels and layers, we can deeply understand the operating principle of WCDMA, and get known to the WCDMA Radio frequency propagation model prediction very easily.

Chapter Three

3 Wireless Propagation Models

Wireless propagation models [33] are very important in cellular networks. The available resources are very limited in cellular networks and we have to make use of them in the best possible manner. An optimized solution is required in order to make use of the spectrum efficiency. This is good in order to improve coverage, capacity and Quality of Service (QoS). The core principle of choosing preeminent and efficient wireless propagation model is to make light of the cost of network while maintaining the QoS in network. In wireless propagation model, we have parameters like path loss, antenna gain, attenuation (rain or fog), SNR etc.

3.1 Introduction

The propagation means transmit the required signal intensity in the given time period and geographic/climatic region over desired distance/area/volume. The wireless propagation model is the relation between the signal radiated and signal received as a function of distance and other variables as shown in Figure 3-1.

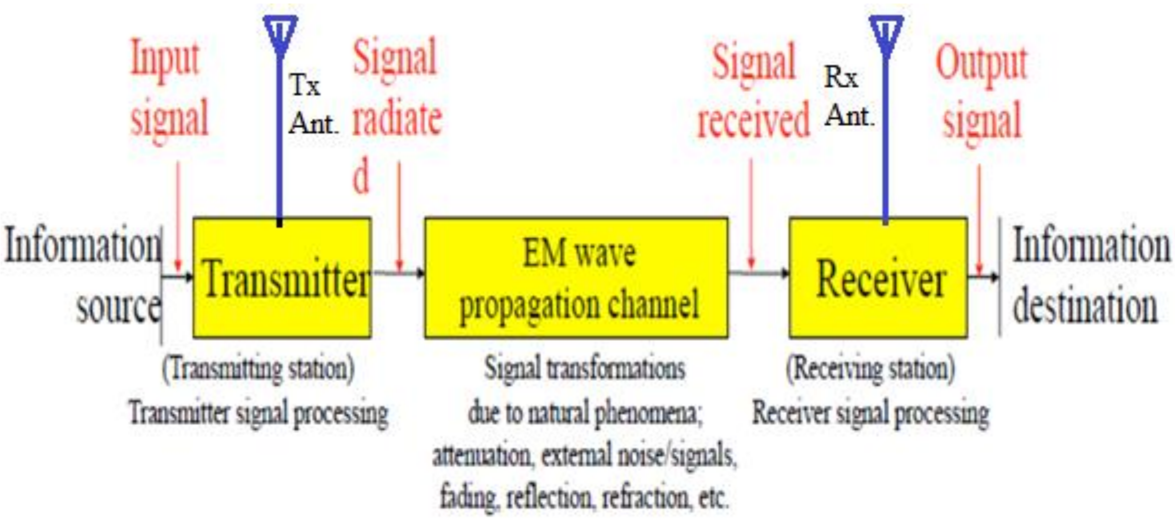


Figure 3-1: Radio transmission [34]

3.2 Radio Wave Components

- **Direct wave**
  - ✓ The wave in free space is called direct wave.
- **Attenuated wave**
  - ✓ The wave attenuated by walls, buildings, atmosphere, is called attenuated in wireless communication. Its frequency is equal or greater than 10 MHz.
- **Reflected wave**
  - ✓ The wave after reflection from ionosphere, ground, passive antenna, wall etc is called as reflected wave. Its frequency is equal or less than 100 MHz.
- **Refracted wave**
  - ✓ The wave which goes through standard refraction, sub refraction, super refraction, ducting, ionized layer refraction, is known as refracted wave. Its frequency is equal or less than 100 MHz.
- **Diffracted wave**
  - ✓ The wave which results after ground diffraction, mountain diffraction, spherical earth diffraction etc, is called diffracted wave. Its frequency is equal or less than 5 GHz.
- **Surface wave**
  - ✓ Its frequency is equal or less than 30 MHz.
- **Scatter wave**
  - ✓ Tropo scatter wave, ionized-layer scatter wave, precipitation-scatter wave are the types of scatter wave.

3.3 Radio Propagation

The mobile communication uses air interface for transmission and reception of signal. The interface between the base station (Node B) and the mobile station (UE) in UMTS is known as *Uu-interface* (UMTS radio interface) which is the propagation path of radio signal between the mobile station and the network. This interface in UMTS is based on WCDMA technology. The UMTS radio interface has different behaviors for different propagation environments. The propagation environment can be classified into outdoor and indoor environment.

The outdoor environment can be further classified into macro-cellular environment and microcellular environment. Depending on the buildings or other obstacles density, a macro-cellular environment contains an urban, suburban and rural type of area.

Propagation model plays an important role in modeling the behavior of radio signal in different propagation environment. There are many propagation models which help in modeling the radio propagation. Each propagation environment has its own propagation characteristics, which can be defined by the following parameters: -

- Multipath Propagation
- Angular Spread
- Delay spread and Coherence Bandwidth
- Fast Fading and Slow Fading
- Propagation Slope

3.3.1 Multipath Propagation

Multipath propagation occurs due to reflections, diffractions, and scatterings from different obstacles such as buildings, street lamps, trees in the radio path. The multipath waves coming from different directions combine at the receiver antenna to give a resultant signal which can vary widely in amplitude and phase depending on the distribution of the intensity and the relative propagation time of the component waves.

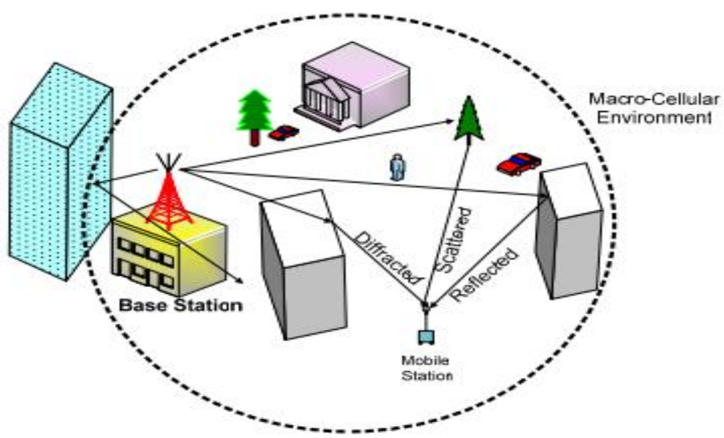


Figure 3-2: Multipath propagation concept

The path exhibit differing attenuations and have different lengths, so that the receiver observes several relatively delayed and attenuated versions of the signal. As the mobile moves around in space, or in case of stationary mobile unit, due to moving obstacles such as cars, people, etc., the structure of the multipath medium changes and spatial variations appear as time variation in the received signal. The Figure illustrates the described propagation scheme in a macro-cellular radio environment, where the base station antennas are typically located above the average roof-top level.

3.3.2 Angular Spread

Angular spread describes the deviation of the signal incident angle. It can be calculated in two planes, horizontal or vertical. The received power from the horizontal plane is still the most important because of obstructing constructions: most of the reflecting surfaces are related to the horizontal propagation and thus multiple BTS to MS propagation paths exist more in horizontal plane.

The vertical angular spread influences, additionally, the base station antenna array tilting angle. The angular spread is also a key parameter when the performance of the adaptive antennas is discussed because the optimization of the Carrier-to-Interference Ratio (CIR) depends strongly on the incident angles of the carrier and on the interference signals. Thus, the performance of the adaptive antennas is lower or more difficult to achieve in the microcellular environments than in the macro-cellular environments.

3.3.3 Delay Spread and Coherence Bandwidth

Due to multipath propagation of the radio signal, the same signal arrives at the receiver end at different times with different angles of arrival which causes the signal to spread in time. The arrival time difference between the first multipath signal and the last one is called the *delay spread (DS)*, as shown in Figure [3-3]. The delay would be unimportant if the entire signal components arrived at the receiver with the same delay. The symbol is therefore still arriving at the receiver when the initial energy of the next symbol arrives, and this energy creates ambiguity in the demodulator of the new symbol which is known as *inter-symbol interference* (ISI).

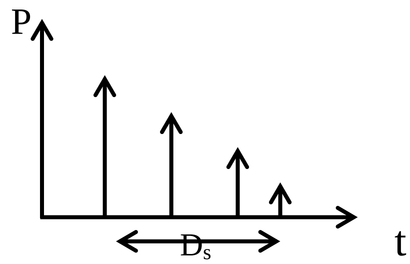


Figure 3-3: Delay spread

The bandwidth over which the channel's transfer function remains virtually constant is called the *coherence bandwidth*. In other words, the maximum bandwidth over which two frequencies of a signal are likely to experience comparable or correlated amplitude fading is called coherence bandwidth. Coherence bandwidth (B_c *hertz*) is related to delay spread ($D_s\ seconds$) as:

$$B_c = 1/(2\pi D_s) \qquad (3.1)$$

The channel is wideband when the signal bandwidth is large compared with the coherence bandwidth.

3.3.4 Fast Fading and Slow Fading

A channel can be classified either as a fast fading or slow fading channel depending upon how rapidly the transmitted radio signal changes as compared to the rate of change of the channel. We can note that the signal strength varies rapidly as time elapsed. It is because either mobile station or the surrounding object is moving due to which multipath effects occurred and the receiver receives different components of same signals at different times.

In *fast fading* channel, the impulse response of the channel changes rapidly within the symbol duration. That is, the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion (also called time selective fading) due to Doppler spreading, which leads to signal distortion. The signal distortion due to fast fading increases with the increase of Doppler spread relative to the bandwidth of the transmitted signal. Therefore, a signal undergoes fading effect if

$$T_S > T_C, B_S < B_D \tag{3.2}$$

Where, T_S is the symbol period, T_C, is the coherence time, $B_S$is the bandwidth of the transmitted signal and $B_D$is the Doppler spread bandwidth.

In *slow fading* channel, the impulse response of the channel changes at a rate much slower than the transmitted radio signal. In this case, the channel may be assumed to be a static over one or several reciprocal bandwidth intervals. In the frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the transmitted signal.
Therefore, a signal goes slow fading if

$$T_S \ll T_C, B_S \gg B_D \tag{3.3}$$

It should be emphasized that the fast fading and the slow fading deal with the relationship between the time rate of change in the channel and the transmitted signal, and not with the path loss models. Fast fading is quite similar in all environments but depends on the speed of the receiver.

3.3.5 Propagation Slope

The propagation slope characterizes the behavior of propagation environment. It indicates that by how much a radio signal is attenuated over a distance in an environment. Attenuation due to propagation limits the usability of the radio signal for the communication purposes. The received power at a distance r from the isotropic radiator in an environment is given by:

$$P_r = \left(\frac{\lambda}{4\pi r}\right)^n P_t G_r G_t(\theta, \emptyset) \tag{3.4}$$

where, λ is signal wavelength in meters, n is the path loss exponent, P_t is the transmitted power, $G_r$is the receiving antenna gain and $G_t(\theta, \emptyset)$ is the transmitting antenna gain where, θ *and* $\emptyset$ are the angles measured in the vertical and horizontal directions respectively. The path loss in dB can be written as:

$$L(dB) = 10log_{10}[\frac{1}{G_r G_t(\theta, \emptyset)}(\frac{4\pi r}{\lambda})^n]$$

$$= 16.22n + 10nlog_{10}(r[Km].f[MHz]) - 10log_{10}G_r G_t(\theta, \emptyset)) \tag{3.5}$$

Where, f is the system frequency given by

$$f.\lambda = c = 3.10^{8} m/sec. \quad (3.6)$$

The path loss exponent (n) in case of free space is 2, i.e. the propagation slope is 20dB/decade, but the path loss exponent changes with the environment according to the values given in Table 3-1.

Table 3-1: An Example of Path Loss Exponents According to Environment Type 3

Environment	**Path Loss Exponent**
Free space	2
Ideal specular reflection	4
Urban cells	2.7-3.5
Urban cells with shadowing	3-5
In building, LOS	1.6-1.8
In building, Obstructed path	4-6
In factory, Obstructed path	2-3

3.4 Radio Signal Path Loss Basics

The signal path loss is essentially the reduction in power density of an electromagnetic wave or signal as it propagates through the environment in which it is travelling.

There are many reasons for the radio path loss that may occur:

Free space loss: The free space loss occurs as the signal travels through space without any other effects attenuating the signal it will still diminish as it spreads out. This can be thought of as the radio communications signal spreading out as an ever increasing sphere. As the signal has to cover a wider area, conservation of energy tells us that the energy in any given area will reduce as the area covered becomes larger.

Absorption losses: Absorption losses occur if the radio signal passes into a medium which is not totally transparent to radio signals. This can be likened to a light signal passing through transparent glass.

Diffraction: Diffraction losses occur when an object appears in the path. The signal can diffract around the object, but losses occur. The loss is higher the more rounded the object. Radio signals tend to diffract better around sharp edges.

Multipath Fading: In a real terrestrial environment, signals will be reflected and they will reach the receiver via a number of different paths as shown in figure 1. These signals may add or subtract from each other depending upon the relative phases of the signals. If the receiver is moved the scenario will change and the overall received signal will be found to vary with position. Mobile receivers (e.g. cellular telecommunications phones) will be subject to this effect which is known as Rayleigh fading.

Terrain: The terrain over which signals travel will have a significant effect on the signal. Obviously hills which obstruct the path will considerably attenuate the signal, often making reception impossible. Additionally, at low frequencies the composition of the earth will have a marked effect. For example, on the Long Wave band, it is found that signals travel best over more conductive terrain, e.g. sea paths or over areas that are marshy or damp. Dry sandy terrain gives higher levels of attenuation.

Buildings and vegetation: For mobile applications, buildings and other obstructions including vegetation have a marked effect. Not only will buildings reflect radio signals, they will also absorb them. Cellular communications are often significantly impaired within buildings. Trees and foliage can attenuate radio signals, particularly when wet.

Atmosphere: The atmosphere can affect radio signal paths. At lower frequencies, especially below 30 - 50MHz, the ionosphere has a significant effect; reflecting (or more correctly refracting) them back to Earth. At frequencies above 50 MHz and more the troposphere has a major effect, refracting the signals back to earth as a result of changing refractive index. For UHF broadcast this can extend coverage to approximately a third beyond the horizon.

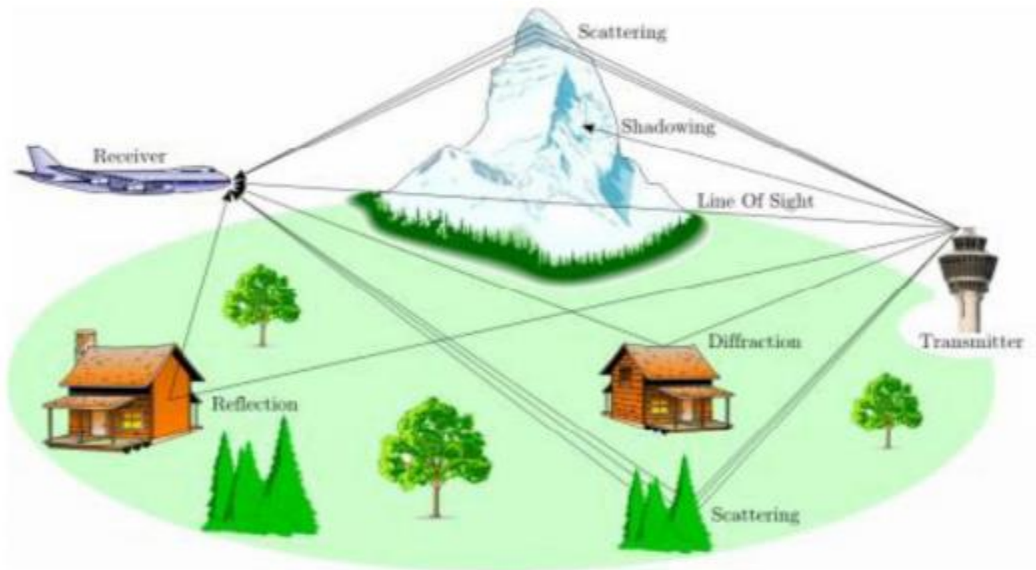


Figure 3-4: Multi-path propagation

3.5 Calculating and predicting path loss in UMTS

One of the main objectives of understanding the different elements that result in the radio signal path loss is to be capable to forecast the loss for a particular path, or to forecast the coverage that may be achieved for a given base station and broadcast station. In spite of this there are many wireless radio coverage prediction software programs and wireless survey tools that are available to predict radio path loss. Most path loss predictions are made using techniques outlined below:

Statistical methods: These methods of predicting signal path loss rely on measured and averaged losses for distinctive types of radio links. Different models can be used for different applications. This type of approach is generally used for cellular network planning, for estimating the coverage of Private Mobile Radio (PMR) links and to plan for broadcast coverage.

Deterministic methods: This approach or method of predicting radio signal path loss and coverage utilizes the basic physical approaches as the basis for the calculations. This type of methods requires taking into consideration all the parameters within a given area and although they tend to give better accurate results, they need much additional data and computational power

3.6 Types of RF/Wireless Propagation Models

The following are the types of RF propagation models.

3.6.1 Free Space Path loss Model

The basic electromagnetic wave propagation mechanisms are free space loss, reflection, diffraction and scattering. Free space loss describes the ideal situation, where the transmitter and receiver have line-of-sight and no obstacles are around to create reflection, diffraction or scattering. In this ideal case the attenuation of the radio wave signal is equivalent to the square of the distance from the transmitter. When the signal has been transmitted in the free space towards the receiver antenna, the power density S at the distance from the transmitter d can be written as [35, 36, 37, 38]:

$$S = \frac{P_t\, G_t}{4\pi d^2} \qquad (3.1)$$

Where: P_t is the transmitted power and $G_t$is the gain of the transmitter antenna. The effective area A of the receiver antenna, which affects the received power, can be expressed as:

$$A = \frac{\lambda^2 G_r}{4\pi} \qquad (3.2)$$

Where A is the wavelength and G_r is the gain of the receiver antenna. The received power density can also be written as:

$$S = \frac{P_r}{A} \qquad (3.3)$$

Combining these equations, previous the format for the received power is

$$P_r \; = \; P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2 \qquad (3.4)$$

The free space path loss is the ratio of transmitted and received power. Here is the equation in simplified format, when the antenna gains are excluded:

$$L \; = \; \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (3.5)$$

And the free space loss converted in decibels

$$L_{dB} = 10log_{10}\left(\frac{4\pi d}{\lambda}\right)^2 \qquad (3.5a)$$

$$L_{dB} = 20log_{10}\left(\frac{4\pi d}{\lambda}\right) \qquad (3.5b)$$

$$L_{dB} = 20log_{10}(4\pi) + 20log_{10}(d) – 20log_{10}(\lambda) \quad (3.5c)$$

Substituting λ (in km) = 0.3/f (in MHz) and rationalizing the equation produces the generic free space path loss formula

$$L_{dB} = 20log_{10}(4\pi) + 20log_{10}(d) – 20log_{10}\left(\frac{0.3}{f}\right) \quad (3.5d)$$

$$L_{dB} = 32.4 + 20log_{10}(f) + 20log_{10}(d) \quad (3.5e)$$

Where f is the frequency in megahertz and d is the distance in kilometers.

In reality the radio wave propagation path is normally a non-line-of-sight situation with surrounding obstacles like buildings and trees. Therefore the applicability of the free space propagation loss is limited. The received signal actually consists of several components, which have been travelling through different paths facing reflection, diffraction and scattering. This effect is called multipath and one component represents one propagation path. The different components, signal vectors, are summarized as one signal considering the vector phases and amplitudes.

The attenuation of the radio wave signal power depends on the frequency band and terrain types between the transmitting and receiving antenna. When estimating the total path loss of the radio signal, the travelled path can be split into sections according to terrain types. As the propagation varies according to the area type, this has to be taken into account in the propagation model. The difference can be explained using the measured correction factor for each terrain type.

One more phenomenon of the mobile environment is the different fading types. Slow fading happens when the radio wave signal is diffracted due to buildings or other big obstacles in the signal path. The receiver, the mobile phone, is in a way in the shadow of these obstacles. Slow fading is log-normal fading and therefore modeled with a Gaussian distribution. The previously mentioned multipath propagation causes short term fades, which can be relatively deep, in the received signal due to the summarized signal vectors, which are having different phases and amplitudes. This fading is known as fast fading or Rayleigh fading. As the second name implies, fast fading can be modeled using the Rayleigh distribution.

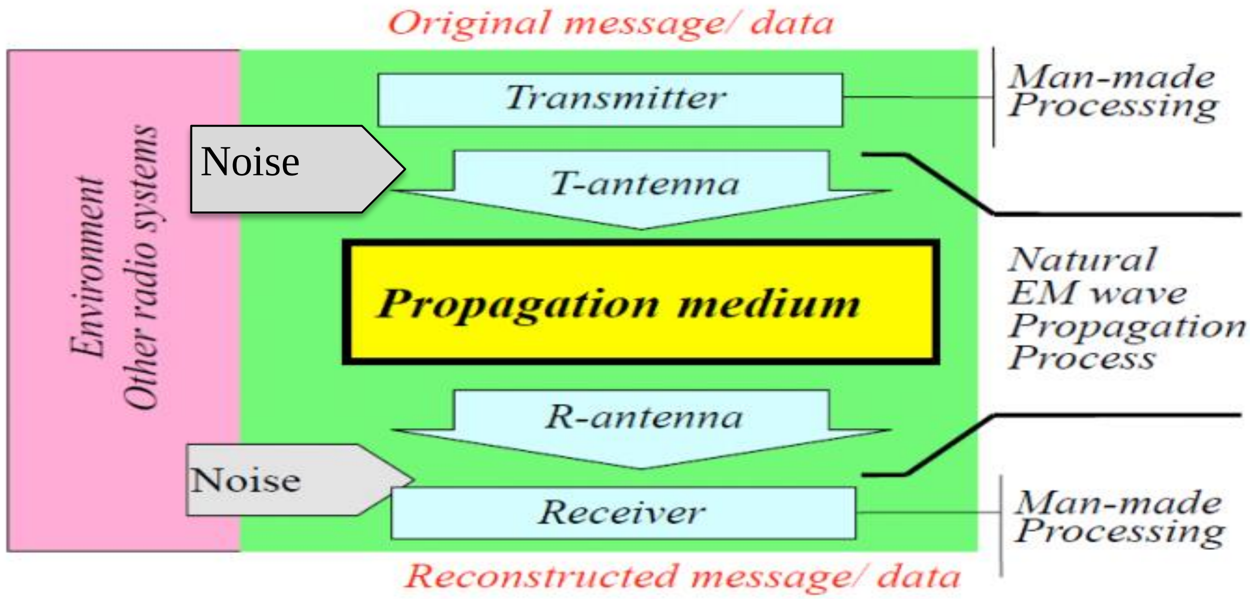


Figure 3-5: Simple radio link model [39]

Generally, there are two types of wireless/RF Propagation models.

- Indoor RF propagation models
- Outdoor RF propagation models

3.6.2 Indoor RF propagation models

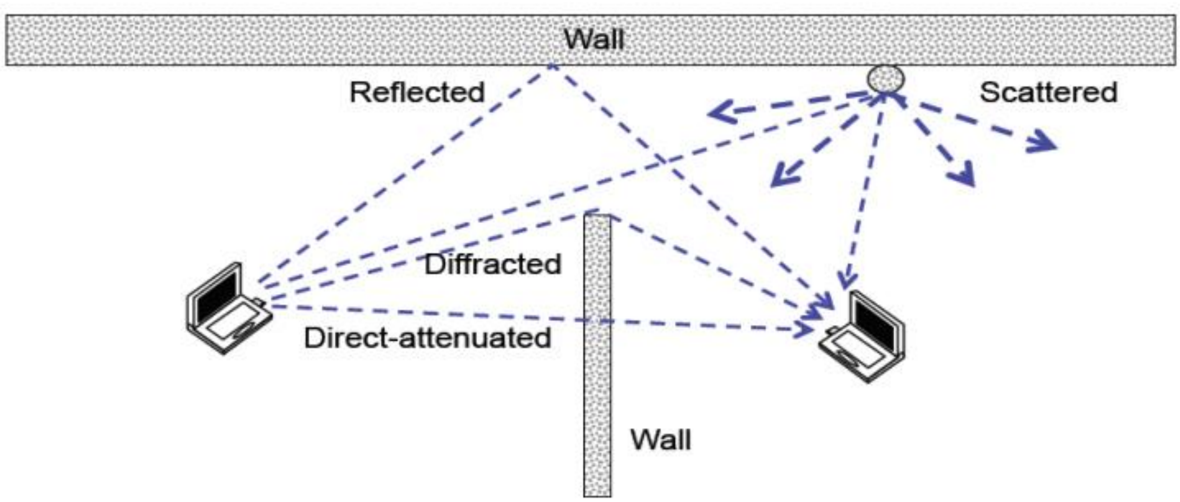


Figure 3-6: Indoor propagation [13]

The following indoor propagation models are used in wireless communication:

- Log-distance path loss model
- ITU model for indoor attenuation
- Keenan-Motley model
- Path loss slope model

The Indoor Propagation can be affected due to following reasons:

- → Effects of obstructions → Energy spreading → Effects of ground → Wavelength
- → Frequency → Polarization → Environment → Climate
- → Weather → Time

3.6.3 Outdoor RF Propagation Models

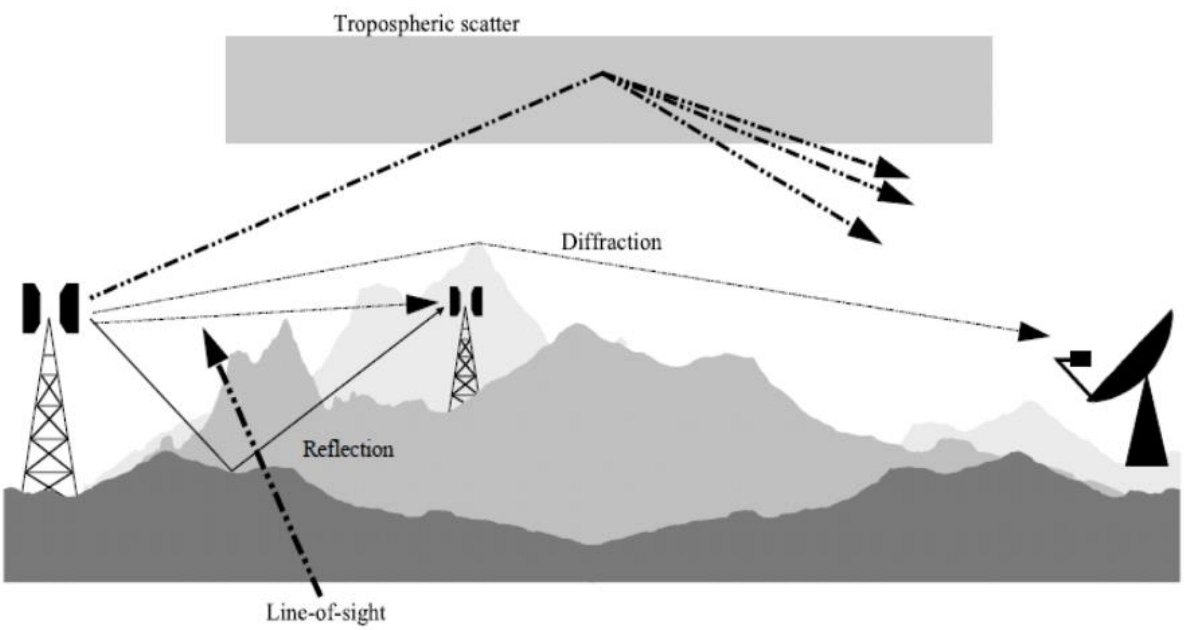


Figure 3-7 : Outdoor propagation [14]

In Wireless Communication the following Outdoor Propagation Models are used:

3.6.3.1 Foliage models

- Updated ITU model
    - Single vegetative obstruction model
    - One woodland terminal model
- Early ITU model
- Weissberger's modified exponential decay model

3.6.3.2 Terrain models

- ITU terrain model
- Longley–Rice model
- Egli model

3.6.3.3 City models

- Lee model (point-to-point)
- Lee model (area-to-area)
- COST 231 Hata model
- Hata model (for open areas)
- Hata model (for suburban areas)
- Hata model (for urban areas)
- Okumura model
- Young model

3.6.3.4 Band-specific models

- The ISM Band (i.e. 2.1 GHz used in UMTS)

Outdoor Propagation can be affected as follows:

➔ Energy spreading → Ionosphere effects → Wavelength → Effects of obstructions

➔ Frequency → Polarization → Environment → Effects of Ground

➔ Climate → weather → Time

➔ Troposphere effects (For clear air and non-clear air)

Chapter Four

4 Radio Frequency Propagation Models in UMTS

4.1 Introduction

Land mobile radio systems are used in a wide variety of scenarios. At one extreme, country police and other emergency services operate over fairly large ares using frequencies in the lower part of the VHF band. The service area may be large enough to require several transmitters, operating in a quasi-synchronous mode, in major cities, to include rural, suburban and urban areas. At the other extreme, in major cities, individual cells within a 900 or 1800MHz cellular radio telephone system can be very small in size, possible less than 1km in radius, and service has to be provided to both vehicle-mounted installations and to hand-portables which can be taken inside buildings.

Having looked at how irregular terrian affects VHF and UHF radio wave propagation and the effects of multipath, now in a position to discuss propagation in built-up areas. This chapter will deal principaly with propagation between base stations and mobiles located at street level; propagation into buildings and totally within buildings. Although losses due to buildings and other man-made obstacles are of major concern, terrian variations also play an important role in many cases.

Within built-up areas, the shadowing effects of buildings and the channelling of radio waves along streets make if difficult to predict the median signal strength. Often the strongest paths are not the most obvious or direct ones and the signal strength in streets that are radial or approximately radial with respect to the direction of the base station often exceeds that in streets which are circumferential. In suburban areas there are fewer large buildings and the channelling effects are less apparent. However foliage effects, often negligible in city centers, can be quite important. Generally, the effects of trees are similar to those of buildings, introducing additional path losses and producing spatial fading.

4.2 Built-up areas: A Classification approach

In situations of practical interest, the environment can be regarded as composed of many different mutually independent scatterer classes or types. Features such as buildings and trees are common and a town might appear as a random collection of buildings, each building bieng a scatterer. Likewise a forest appears as a random collection of trees. If the stastical properties of groups of clusters of individual scatterers are known, as well as the scatterer population per group, then it is possible to drive quantitative descriptions of the environment using stastics [2].

An environment classification method can be based on this approach. Any given mobile radio service area can be viewed as a mixture of envirnments (e.g. a mixture of urban, suburban and rural localities).

In considerng the effects of the environmet, six factors are useful in classifying land usage:

- Building density (percentage of area covered by buildings)
- Building size (area covered by a building)
- Building height
- Building location
- Vegetation density
- Terrian undulations

In association with a computer-based simulation, a more refined method of categorisation has been proposed [42]. From a digitised map it is possible to extract the following land usage parametrs:

- Building location (with respect to some reference point
- Building size, or base area
- Total area occupied by buildings
- Number of buildings in the area concerned
- Terrian heights
- Parks and/or gardens with trees and vegetation

Three classifications of envirnment are also proposed, with subclasses as appropriate:

- Class 1 (rural)
    a. Flat

    b. Hilly
    c. Mountains
- Class 2 (suburban)
    a. Residential with some open spaces
    b. Residential with little or no open space
    c. High-rise residential
- Class 3 (urban and dense urban)
    a. Shopping area
    b. Commercial area
    c. Industrial area

In the last chapter, RF Propagation models [42] were discussed in perspective of general cellular networks. Here, the focus will be on best choice of RF models in UMTS network. There is a similarity between architectures of UMTS and general cellular networks. Hence, RF model is of great importance in UMTS as well. The main function of choosing best RF model is to ensure the QoS. The optimal solution in designing and planning a network is critical due to the limitation of resources. This thesis studied an outdoor RF propagation models in UMTS network a frequency bands 2100MHz.

4.3 Outdoor RF Propagation Models for UMTS

The prediction of path loss is a very important step in planning a mobile radio system, and accurate prediction methods are needed to determine the parameters of a radio system which will provide efficient and reliable coverage of a specified service area. In order to make predictions we need a proper understanding of the factors which influence the signal strength and some of these have already been covered in this chapter. Other factors exist however, for example in urban areas we have to account for the effect of buildings and other man-made obstacles. In rural areas, shadowing, scattering and absorption by trees and other vegetation can cause substantial path losses, particularly at higher frequencies.

Existing prediction models differ in their applicability over different terrian and environmental conditions; some purport to have general applicability, others are restricted to more specific situations. What is certain is that no one model stands out as being ideally suited to all environments, so careful assessment is normally required. The remainder of this chapter inthis thesis is a brief survey of some better-known methods.

The following RF path loss propagation models are used as outdoor propagation in this thesis:

- Okumura Hata Path Loss Model
- SUI Path Loss Model
- COST- 231 Hata Model
- COST-231 Walfisch-Ikegami Model
- Ericsson 9999 Model
- The Lee model

4.3.1 Okumura-HATA Model

Okumura published an emperical prediction method for signal strength prediction. The basis of the method is that the free space path loss between the points of interest is determined and to the value of A_{mu} (f,d) obtained from Figure 4-1. A_{mu} is the median attenuation, relative to free space in an urban area over quasi-smooth terrian (interdecile range < 20 m) with a base station effective antenna height h_{te} of 200 m and a mobile antenna height h_{re} of 3 m. It is expressed as a function of frequency (100-3000 MHz) and distance from the base station (1-100 km). Correction factors have to be introduced to account for antennas not at the reference heights, and the basic formulation of the technique can be expressed as

$$L_{50}\,(\text{dB}) = L_f + A_{mu} + H_{tu} + H_{ru} \tag{4.1}$$

H_{tu} is the base station antenna height gain factor; it is shown in Figure 4-2 as a function of the base station effective antenna height and distance. H_{ru} is the vehicular antenna height gain factor and is shown in figure 4-3. Figure 4-2 shows that H_{tu} is of order 20dB/decade, i.e. the received power is proportional to h_{te}^2, in agreement with the plane earth equation. From figure [4-3] it is apparent that the same relashinship applies in respect of H_{ru} if h_{re} > 3 m; however, H_{ru} only changes by 10 dB/decade if h_{re} < 3 m.

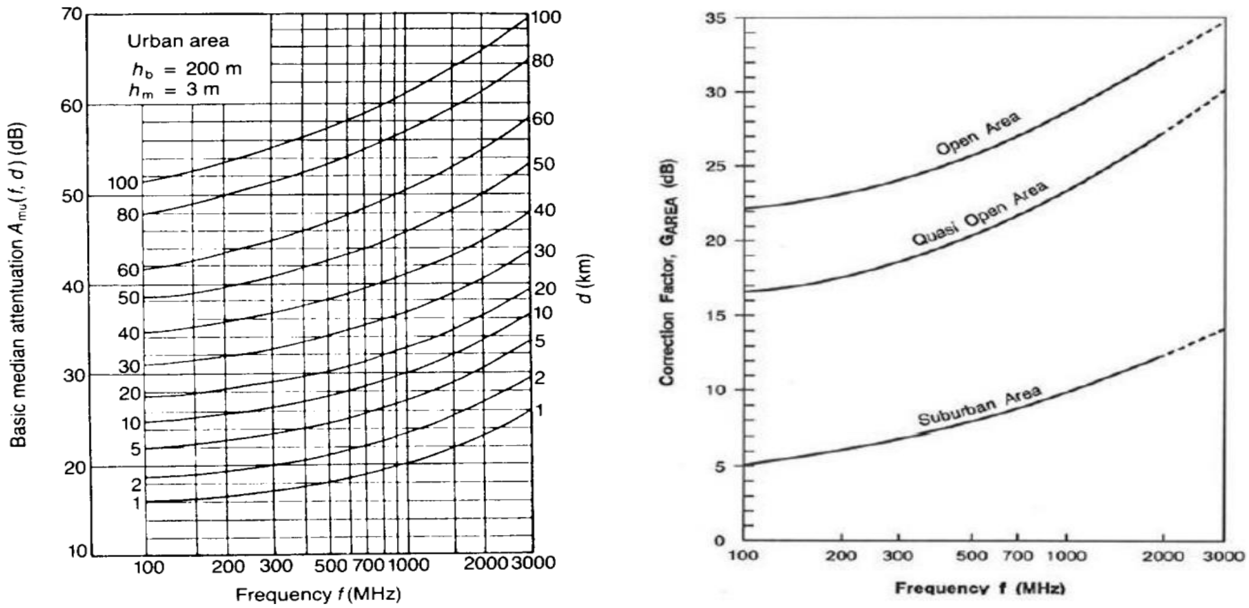


Figure 4-1: Basic median path loss and correction factor relative to free space in urban areas over quasi-smooth terrain (after Okumura)

Further correction factors are also provided, in graphical form, to allow for steet orientation as well as transmisson in suburban and open (rural) areas and over irregular terrian. These must be added or subtracted as appropriate. Irregular terrian is further subdivided into rolling hilly terrian, isolated mountain, general sloping terrian and mixed land-sea path. The terrian-related parameters that must be evaluate to determine the various correction factors are:

- *Effective base station antenna height (h_{te})*: this is the height of the base station anenna above the average ground level calculated over the range interval 3-15 km (or less if the range is below 15 km) in a direction towards the reciever (Figure 4-4).
- *The Terrian undulation height (Δh)*: This is the terrrian irregularity parameter, defined as the interdecile height taken over a distance of 10 km from the receiver in a direction towards the transmitter.
- *Isolated ridge height*: If the propagation path includes a single obstructing mountain, its height is measured relative to the average ground level between it and the base station.
- *Average slope*: If the ground is genrally slopping, the angle Θ (positive or negative) is measured over 5-10 km.

- *Mixed land-sea path parameter*: This is the percentage of the total path length covered with water.

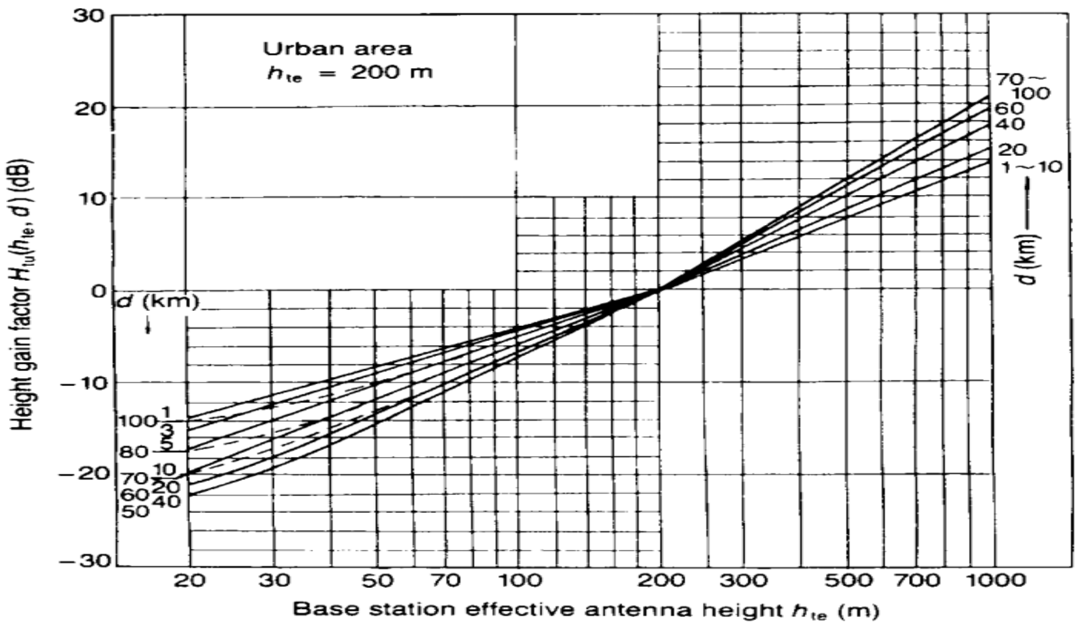


Figure 4-2: Base station height/gain factor in urban areas as a function of range (reference height = 200 m).

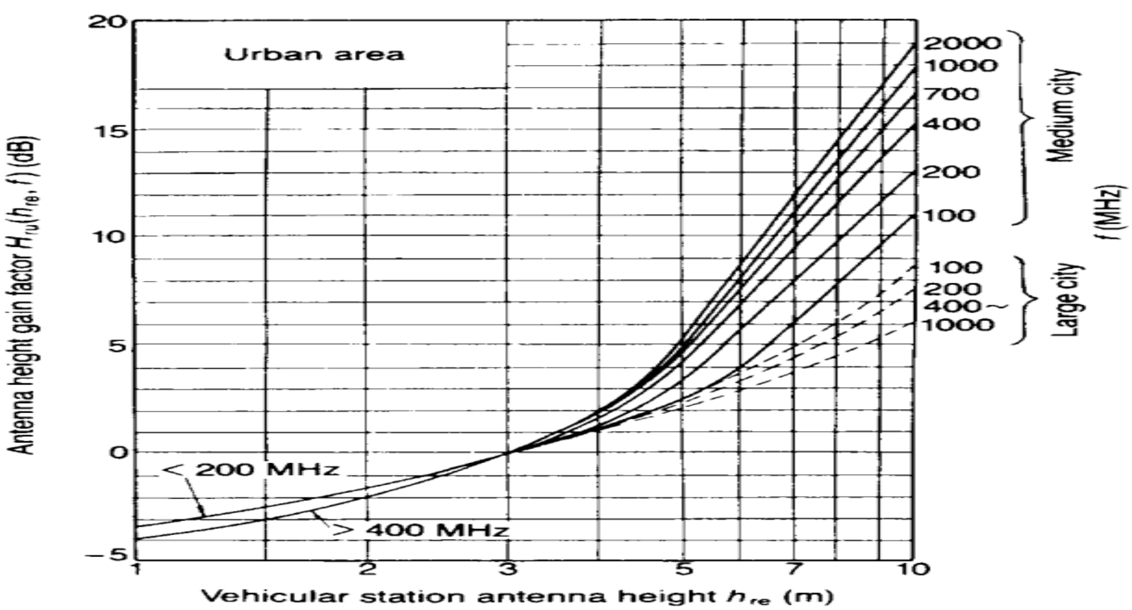


Figure 4-3: Vehicular antenna height/gain factor in urban areas as a function of frequency and urbanization (reference height = 30m).

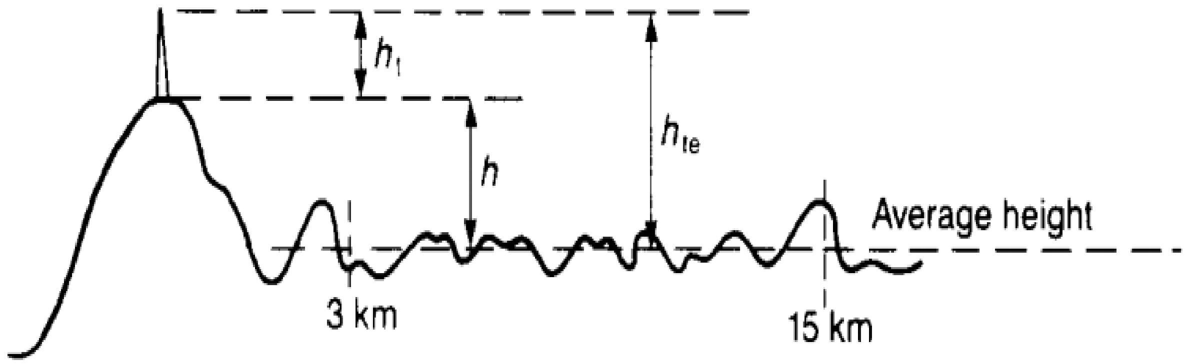


Figure 4-4: Method of calculating the effective base station antenna height.

There are **two modes of operation**. In quasi-smooth terrian the required input parameters include frequency, antenna heights, range, type of environment, size of city and street orientation. For irregular terrian a number of terrian-related paramters, as defined above, may also be required. If a terrian database is also stored in the computer then a computer routine can determine the types of irregularity from the path profile and hence derive the appropriate terrian parameters.

The Okumura-Hata model is a well-known propagation model, which can be applied for a macro cell environment to predict median radio signal attenuation. Having one component the model uses free space loss. The Okumura-Hata model is an empirical model, which means that it is based on field measurements.

Okumura performed the field measurements in Tokyo and published results in graphical format. HATA applied the measurement results into equations. The model can be applied without correction factors for quasi-smooth terrain in an urban area but in case of other terrain types correction factors are needed. The weakness of the Okumura-Hata model is that it does not consider reflections and shadowing. The parameter restrictions for this model are [43]:

- Frequency f: 150-1500 MHz, extension 1500-2100 MHz
- Distance between MS and BTS d: 1-20 km
- Transmitter antenna height H_b: 3-200 m
- Receiver antenna height H_m:1-10 m

The Okumura-Hata model for path loss prediction can be written as:

$$P_L(dB) = A + Blog_{10}(f) - 13.82log_{10}(H_b) - a(H_m) + [44.9 - 6.5log_{10}(H_b)]log_{10}(d) + L_{other} \quad (4.1)$$

Where

- f is the frequency (MHz),
- H_b is the base station antenna height (m),
- $a(H_m)$ is the mobile antenna correction factor,
- d is the distance between the BTS and MS (km) and
- L_{other} is an additional correction factor for area type correction.

The correction factor for the MS antenna height is represented as follows for a small or medium sized city:

$$a(H_m) = [1.1log_{10}(f) - 0.7]H_m - [1.56log_{10}(f) - 0.8] \quad (4.1a)$$

And for a large city:

$$a(H_m) = \begin{cases} 8.29[log_{10}(1.54H_m)]^2 - 1.1: & f \leq 200\ MHz \\ 3.2[log_{10}(11.75\ H_m)]^2\ - 4.97: & f \geq 400\ MHz \end{cases} \quad (4.1b)$$

Where H is the MS antenna height:

$$1 \leq H_m \leq 10 \qquad (H_m \text{ in metres}) \quad 4.1c)$$

The parameters A and B are dependent on the frequency as follows:

$$A = \begin{cases} 69.55, & f = 150 - 1500\ MHz \\ 46.30, & f = 1500 - 2000\ MHz \end{cases} \quad (4.1d)$$

$$B = \begin{cases} 26.16, & f = 150 - 1500\ MHz \\ 33.90, & f = 1500 - 2000\ MHz \end{cases}$$

The Okumura-Hata model is valid for the frequency ranges 150-1500 MHz and 1500-2100 MHz. The range for the base station antenna height is from 30 to 200 meters, the mobile antenna height from 1 to 10 meters and the cell range, i.e. the distance between the BTS and MS, from 1 to 20 km. With the additional correction factor (L_{other}) the Okumura-Hata model can be applied for all terrain types, meaning different morphological areas. The correction factors for each area are received as a result of model tuning including field measurements in the particular areas [43].

4.3.2 COST-231 HATA Model

The HATA model is introduced as a mathematical expression to mitigate the best fit of the graphical data provided by the classical Okumura model. HATA model is used for the frequency range of 150 MHz to 1500 MHz to predict the median path loss for the distance d from transmitter to receiver antenna up to 20 km, and transmitter antenna height is considered 30 m to 200 m and receiver antenna height is 1 m to 10 m. To predict the path loss in the frequency range 1500 MHz to 2100 MHz COST 231 Hata model is initiated as an extension of HATA model. It is used to calculate path loss in three different environments like urban, suburban and rural (flat).

This model provides simple and easy ways to calculate the path loss. Although our working frequency range (2100 MHz) is outside of its measurement range, its simplicity and correction factors still allowed to predict the path loss in this higher frequency range. The basic path loss equation for this COST-231 Hata Model can be expressed as [43]:

$$PL = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - ah_m + [44.9 - 6.55log_{10}(h_b)]log_{10}(d) + C_m \quad (4.2)$$

Where: d is distance between transmitter and receiver antenna (km)

f is frequency (MHz)

h_b is transmitter antenna height (m)

The parameter C_m has different values for different environments like 0 dB for suburban and 3 dB for urban areas and the remaining parameter ah_m is defined in urban areas as [1]:

$$ah_m = 3.2[log_{10}(11.75h_r)]^2 - 4.97, \quad for\ f > 400MHz \quad (4.2a)$$

The value for ah_m in suburban and rural (flat) areas is given as [1]:

$$ah_m = [1.11log_{10}(f) - 0.7]h_r - [1.5log_{10}(f) - 0.8] \quad (4.2c)$$

Where: h_r is the receiver antenna height in meter.

4.3.3 COST-231 Walfisch-Ikegami Model

This model is a combination of J. Walfisch and F. Ikegami model. The COST 231 project further developed this model. Now it is known as a COST 231 Walfisch-Ikegami (W-I) model. This model is most suitable for flat suburban and urban areas that have uniform building height (see figure 4-5). Among other models like the HATA model, COST 231 W-I model gives a more precise path loss. This is as a result of the additional parameters introduced which characterized the different environments. It distinguishes different terrain with different proposed parameters. The equation of the proposed model is expressed in [43]:

For LOS condition

$$PL_{Los} = 42.6 + 20log_{10}(f) + 26log_{10}(d) \quad (4.3)$$

For N-LOS condition

$$PL_{NLOS} = \begin{cases} L_{FSL} + L_{rts} + L_{msd} & for\ urban\ and\ suburban \\ L_{FSL} & ,\quad if\ L_{rts} + L_{msd} > 0 \end{cases} \quad (4.4)$$

Where:

$$L_{FSL} = free\ space\ loss$$

$$L_{rts} = roof\ top\ to\ street\ diffraction$$

$$L_{msd} = multi\ screen\ diffraction\ loss$$

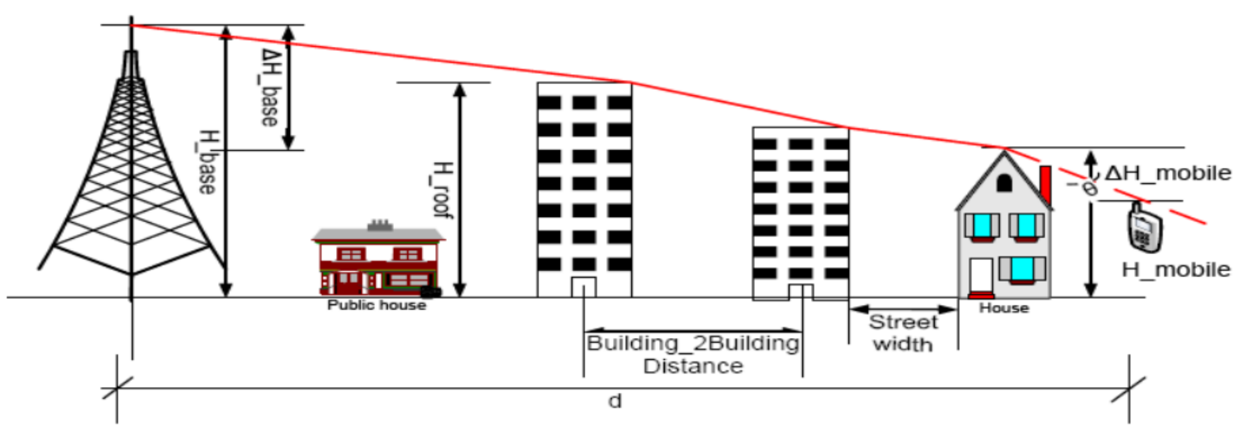


Figure 4-5: COST-231 W-I Model

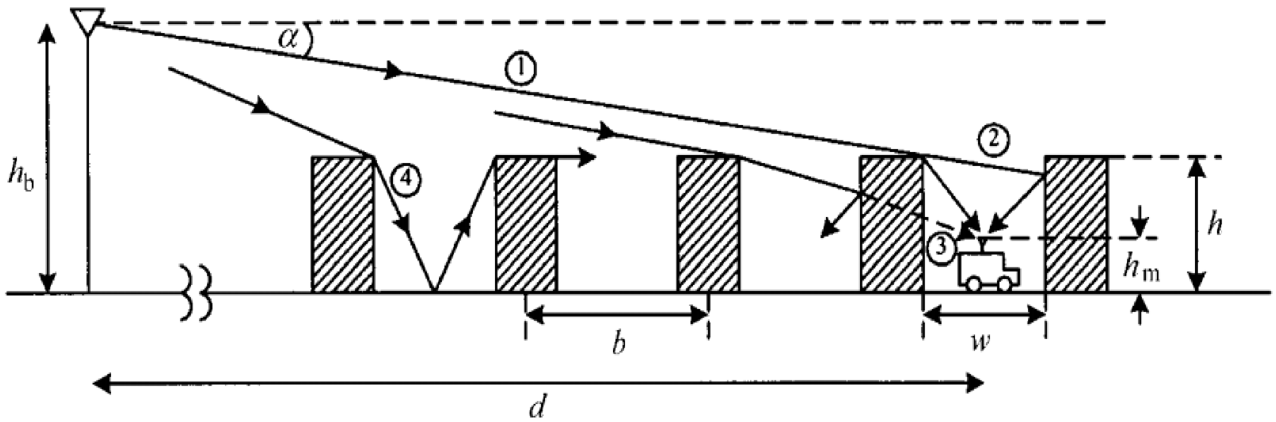


Figure 4-6: Geometry of rooftop diffraction

Free Space Loss:

$$L_{FSL} = 32.4 + 20log_{10}(f) + 20log_{10}(d) \quad (4.5)$$

Roof top to street diffraction:

Roof top to street diffraction loss is calculated by considering street width (w) and Street orientation angel (θ) with respect to the direct radio path.

$$L_{rts} = \begin{cases} -16.9 - 10\log(w) + 10\log(f) + 20\log(h - H_{mobile}) + L_{ori} \\ L_{LSF} \quad\quad if\ L_{rts} + L_{msd} > 0 \end{cases} \quad (4.6)$$

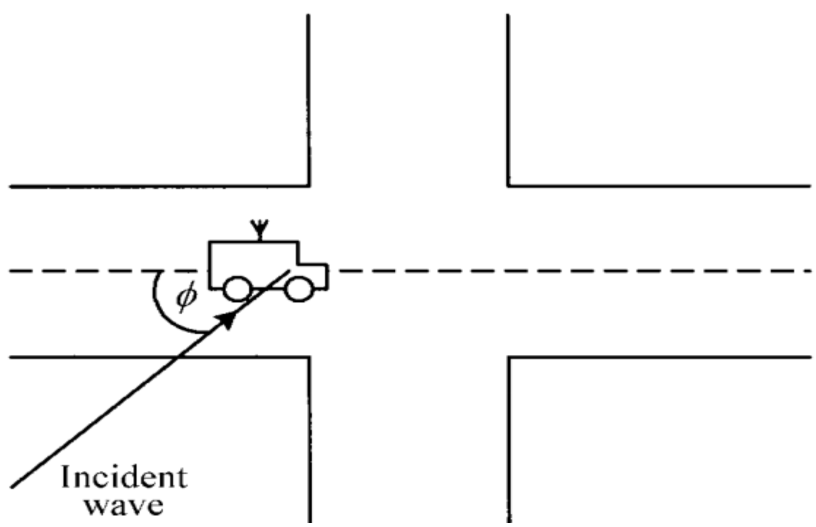


Figure 4-7: Defining the street orientation angle φ

$$L_{ori} = \begin{cases} -10 + 0.354 & 0° \leq \emptyset < 35° \\ 2.5 + 0.075(\varphi - 35) & 35° \leq \emptyset < 55° \\ 4.0 - 0.114(\varphi - 55) & 55° \leq \emptyset < 90° \end{cases} \quad (4.7)$$

Note: L_{ori} is a factor which has been estimated from only a very small number of mesurements. The multiple-screen diffraction loss has been estimated by Walfisch and Bertoni for the case when the base antenna is above the rooftops, i.e. $h_b > h$. This has also been extended by COST to the case when the antenna is below rooftop height, using an emperical function based on measurements.

Note that in the Figure,

$$\Delta H_{mobile} = H_{roof} - H_{mobile} \quad and,$$

$$\Delta H_{base} = H_{base} - H_{roof}$$

d is the distance between the transmitter and receiver (in kilometers), f is central frequency (in MHz). In addition, except for the distance between the transmitter and the receiver, all distance related parameters are in meter. Other than the “”; all distance related parameter units are in meter.

The **multi-screen diffraction loss** is caused by propagation from the BTS to the rooftop, which is closest to the MS:

$$L_{msd} = L_{bsh} + K_a + K_d \log(d) + K_f \log(fc) - 9\log(b) \quad (4.8)$$

Where:

$$L_{bsh} = \begin{cases} -18\log[(1 + (h_{BTS} - h_{roof})]: & h_{BTS} > h_{roof} \\ 0: & h_{BTS} < h_{roof} \end{cases} \quad (4.8a)$$

$$K_a = \begin{cases} 54: & h_{BTS} > h_{roof} \\ 54 - 0.8(h_{BTS} - h_{roof}): & d \geq 0.5 \; and \; h_{BTS} \leq h_{roof} \\ 54 - \frac{0.8(h_{BTS} - h_{roof})}{0.5} d: & d < 0.5 \; and \; h_{BTS} \leq h_{roof} \end{cases} \quad (4.8b)$$

$$K_d = \begin{cases} 8: & h_{BTS} > h_{roof} \\ 18 - 15 \frac{(h_{BTS} - h_{roof})}{h_{BTS} - h_{MS}}: & h_{BTS} < h_{roof} \end{cases} \quad (4.8c)$$

$$K_f = -4 + \begin{cases} 0.7(\frac{fc}{925} - 1): & medium\ size\ cities\ and\ suburban\ centers\ with\ mediun\ tree\ density \\ 1.5\left(\frac{fc}{925} - 1\right): & urban\ city \end{cases} \quad 4.8d)$$

The term K_a represents the increase in path loss when the base station antenna is below rooftop height. The terms K_d and K_f allows for the dependence of the diffraction loss on range and frequency, respectively. If data is unvailable the following default values are recommended:

$$h = 3\text{m} * (\text{number of floors}) + \text{roof of height}$$

$$roof\ height = \begin{cases} 3\ m & for\ pitched\ roofs \\ 0\ m & for\ flat\ roofs \end{cases}$$

$$b = 20\text{-}50\ \text{m}$$

$$w = b/2$$

$$\varphi = 90^{o}$$

The COST model is restricted to the following range of parametrs:

f_c	800 to 2000 MHz
h_b	4 to 50 m
h_m	1 to 3 m
d	0.02 to 5 km

It gives predictions which agree quite well with measurements when the base station antenna is above rooftop height, producing mean errors of about 3 dB with standard deviations in the range 4-8 dB. However, the performance deteriorates as h_b approaches h_r and is quite poor when $h_b \ll h_r$. The model, as it stands, might therefore produce large errors in the microcellular situation.

Using the above series of formulas, the propagation loss is calculated from the transmitter to the receiver; and it is found to be dependent on parameters such as building height, building separation distance, street width, height of the transmitter and the receiver and also the transmission frequency and the distance between the transmitters to the receiver. Whereas COST 231 Hata model is only dependent on the transmission frequency, distance between the transmitter to the receiver, and mainly the building height.

4.3.4 SUI Path Loss Model

The Stanford University Interim (SUI) Path Loss model [44] has been developed by IEEE for IEEE 802.16. This model is used for frequencies above 1900 MHz. As UMTS will be using frequency band of 900 MHz and 2100 MHz, so it is a suitable solution for UMTS network. In this propagation model, we have three different types of areas. These are called as terrain A, B and C. Terrain A represents an area with highest path loss which describes an urban area. Terrain B represents an area with moderate path loss which describes a sub-urban area. Terrain C represents the least path loss. Table 4-1 presents the terrains and the factors used in SUI model.

The Path Loss is given by:

$$PL_{SUI} = A + 10\gamma log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + S \quad (4.9)$$

Where:

PL_{SUI} = $Path\ Loss,\ in\ SUI\ Model,\ measured\ in\ dB$

A = $Free\ Space\ Loss,\ measured\ in\ dB$

d = $Transmitter\ to\ Receiver\ separation\ (km)$

d_o = $100m\ Used\ as\ a\ Reference$

X_f = $Correction\ factor\ for\ frequency$

X_h= $Correction\ factor\ for\ BS\ height$

S = $Shadowing$

γ = $Path\ loss\ component$

$\boldsymbol{\gamma}$ factor is given as:

$$\gamma = a - bh_b + \frac{c}{h_b} \quad (4.9a)$$

Where:

b_h= $Height\ of\ Base\ Station\ BS$

Where **a**, **b** and **c** describes the terrain, and there values are selected from Table 4-1.

Table 4-1: Different terrains and parameters for SUI model [44]

Parameters	*Terrian A*	*Terrian B*	*Terrian C*
A	4.6	4	3.6
B	0.0075	0.0065	0.005
C	12.6	17.1	20

Where:

$Terrian\ A = Urban\ Area$

$Terrian\ B = Sub - Urban\ Area$

$Terrian\ C = Rural\ Area$

The frequency correction factor is given as:

$$X_f = 6.0log_{10}(\frac{f}{2000}) \quad (4.9b)$$

For terrain A and B, correction factor of BS height is explained in following expression:

$$X_h = -10.8log_{10}(\frac{h_r}{2000}) \quad (4.9c)$$

For terrain C, the correction factor for BS height is given by the following expression:

$$X_h = -20log_{10}(\frac{h_r}{2000}) \quad (4.9d)$$

The shadowing factor is given by:

$$S = 0.65(log_{10}f)^2 - 1.3log_{10}f + \alpha \quad (4.9e)$$

Where:

$\alpha = 5.2\ dB\ for\ Terrain\ A\ and\ B\ and\ 6.6\ dB\ for\ (Terrain\ C)$

$h_r = Height\ of\ Receiver\ Antenna$

4.3.5 Ericsson 9999 Model

The Ericsson 9999 model [15] is in fact an extend version of Hata model and implemented by Ericsson in which we can adjust parameters according to the given scenario.

The path loss is given by:

$$PL_{(Eric)} = a_o + a_1log_{10}(d) + a_2log_{10}(h_b) + a_3log_{10}(h_b)log_{10}(d) - 3.2\{log_{10}(11.75h_r)\}^2 + 44.49\{log_{10}(f)\} - 4.78\{log_{10}(f)\}^2 \quad (4.10)$$

$PL\ (Eric) = Path\ Loss,\ in\ Ericsson\ Model,\ measured\ in\ dB$

$a0$, $a1$, $a2$ and $a3$ are values, which are changed according to the environments (i.e. areas). For different areas, the parameters are described in following Table 4-2.

Table 4-2: Parameters and Terrains for Ericsson 9999 Model [46]

Parameters	Rural Area	Sub-Urban Area	Urban
a_o	45.95	43.20	36.2
a_1	100.6	68.93	30.2
a_2	12.0	12.0	12.0
a_3	0.1	0.1	0.1

4.3.6 The Lee model

A propagation model described by Lee is intended for use at 900 MHz, but is it also intended to use above 2000 MHz and operates in two modes, an area-to-area mode and a point-to-point mode.
In the first case the prediction is based on three parameters:

- The median transmission loss at a range of 1km, L_o
- The slope of the path loss curve, γ dB/decade
- An adjustment factor, F_o

Hence the median loss at a distance d is given by

$$L_{50}(dB) = L_o + \gamma log_{10}(d) + F_o \quad (4.11)$$

Values of L_o and γ derived from experiments are listed in Table 4-3 and in making predictions it is necessary to select values from the table by comparing the environment under consideration with the reference environment that most closely resembles it. It is interesting to note that the value of γ for urban and suburban areas is always quite close to 40 dB/decade.

The experimental results on which Table 4-3 is based were obtained using a transmission system with the following parameters:

- Carrier frequency = 900 MHz/ >2000 MHz
- Base station antenna height = 30.48 m
- Transmitter power = 10 W
- Base station antenna with respect to $\lambda/2$ dipole = 6 dB
- Mobile antenna height = 3 m

The adjustment factor F_o is intended to compensate for using different values of these parameters and is expressed as

$$F_o = F_1 F_2 F_3 F_4 \tag{4.12}$$

The values of these various factors are given by

$$F_1 = \left(\frac{actual\ base\ station\ antenna\ height}{reference\ base\ station\ height}\right)^2 \tag{4.12a}$$

$$= \left(\frac{actual\ base\ station\ antenna\ height}{30.5}\right)^2$$

$$F_2 = \frac{actual\ transmitter\ height\ (W)}{10} \tag{4.12b}$$

$$F_3 = \frac{actual\ gain\ of\ base\ station\ antenna}{4} \tag{4.12c}$$

Table 4-3: Propagation parameters for Lee's model

Environment		$L_o(dB)$	γ
Free space		91.3	20
Open (rural) space		91.3	43.5
Suburban		104.0	38.5
Urban area	Philadelphia	112.8	36.8
	Nework	106.3	43.1
	Tokyo	128.0	30
	Others	101.3	44.3

For F_3 the gain is measured with respect to a $\lambda/2$ dipole and the reference antenna gain is 6 dB(= 4). F_4 compensates for changes in the mobile antenna height. It can be determined in the same manner as F_1 for heights above 10 m, but for heights below 10 m the ratio heights is used rather than the ration of $(heights)^2$; compare with Okumura. Lee also suggested that a change in transmission frequency can be accommodated by using a factor of the form $(f/f_o)^n$ but was not specific about the value of n. However, the work of Okumura and Young suggests a value between 2 and 3.

In the more refined point-to-point mode, **Lee's model** takes some account of the terrian. Over unobstructed paths the major task is to determine an appropriate value for the effective base station antenna height. In hilly terrian there are two possible teflection points in Figure 4-7; the effective one is the point closer to the mobile. An effective height can be found by extending the ground plane in this region back to the base station location. This may be greater than the actual height above the local ground, as in Figure 4.7, or less. The effective height is then used to correct eqn (4.12) using the expression

$$L'_{50} = L_{50} + 20log_{10}(h_e/30) \quad (4.13)$$

As the mobile moves, the effective base station antenna heifht changes and Figure 4.8(a) illustrates some of the possibilities. A separate evaluation of equation (4.13) has to be made in each of these situations, hence the term 'point-to-point prediction'. Figure 4.8(b) shows the difference between the point-to-point model and predictions for a flat suburban area with γ = 38.6 dB/decade. The trend is as expected: for positions C to G the value of h_e is greater than the physical height above local ground, so the predicted loss is smaller; for positions H and I the value of h_e is less than the actual height. For obstructed paths, a terrian loss can be added using any of the methods. Incorporating terrian information can make a substantial difference to the predictions (Figure 4.8 (b) and the accuracy is generally increased. The standard deviation of error in the area mode is claimed to be 8 dB but in the point-to-point mode this is reduced to less than 3 dB.

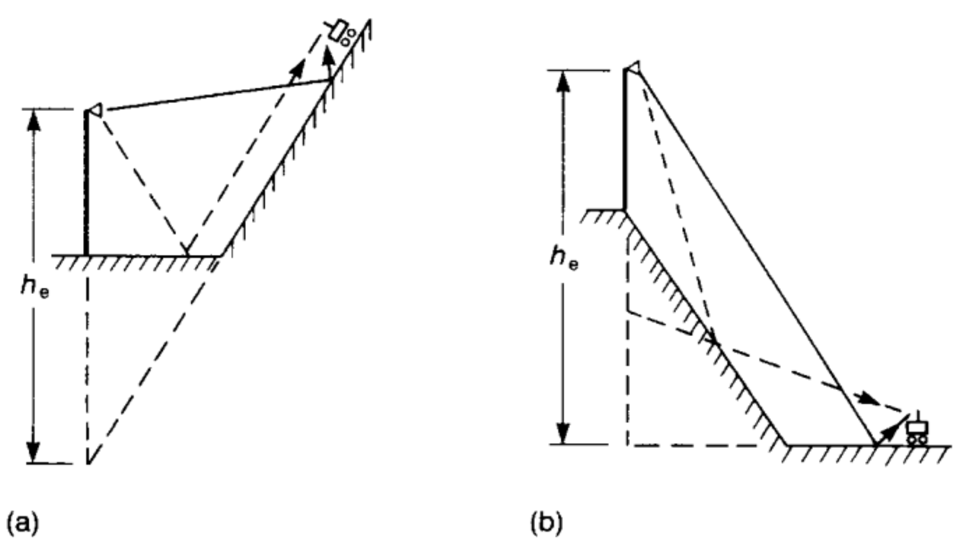


Figure 4-8: Calculating the effective base station antenna height in two types of hilly terrain.

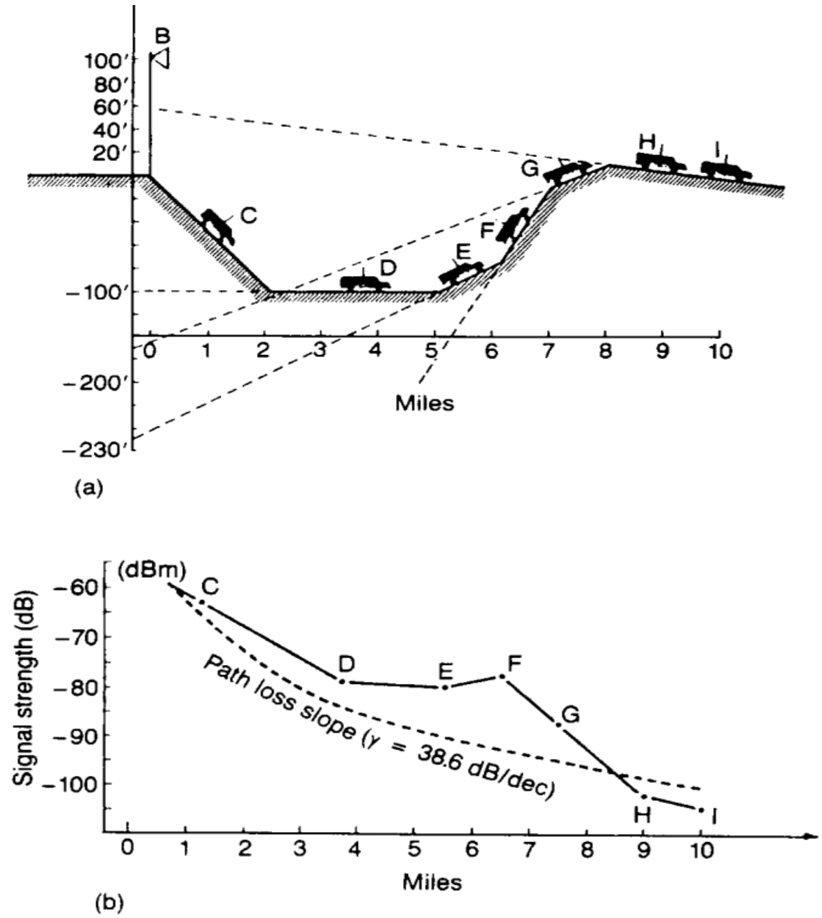


Figure 4-9: Influence of terrain on effective antenna height for different positions (after Lee): (a) hilly terrain contour, (b) point-to-point

Chapter Five

5 Simulation Results and Analysis

The radio propagation model describes the behavior of the signal when it is being transmitted from the transmitter towards the receiver. It gives a relation to the distance between the transmitter & receiver and the path loss. From the above relation, one can get an idea about the acceptable path loss and the maximum cell range. The path loss depends on different terrains and environment (urban, rural, dense urban, suburban, open, forest, sea etc) frequencies, atmospheric situation, and distance between transmitter and receiver.

This part discuss the simulation results of the radio frequency propagation models for a calculated data and the measured results that have been taken from the drive test on MATLAB, before that the site layout and the computational zones obtained from the ATOLL simulation software.

5.1 Simulators/Software used

Nemo Analyzer

Nemo Analyze for professional post-processing of drive test data

Nemo Analyze is a highly efficient and fully scalable analysis tool for benchmarking, automated troubleshooting, and statistical reporting based on drive test data. For benchmarking, it's predetermined report templates help compare KPIs from different operators, technologies, and time frames, and visualize the results in a single report. Nemo Analyze supports all the major network technologies.

Versatile drive test post-processing

Nemo Analyze is the ideal post-processing solution for data produced by Nemo tools. Nemo Analyze's support for CSV (Character-Separated Value) format also allows importing of ASCII data into the database, enabling for instance Wire shark/Ethereal and network counter data to be correlated and post-processed together with Nemo drive test data. Nemo Analyze supports 64-bit platforms Windows®. Integrating Nemo Analyze with other Nemo tools provides a complete automated data processing chain from raw measurement data to automatically generated results in workbook format.

Actix Analyzer

Actix Analyzer is a software application running under Microsoft Windows on a PC, which provides a series of analysis tools for post-processing cellular network data. The tools are designed to address applications such as:

- Network performance optimization
- Feature testing
- Service validation
- Problem diagnosis and analysis
- Network bench-marking
- Competitive analysis

Atoll Simulator software

Atoll Planning Tool was used in this research; Atoll is an open, scalable, and flexible multi-technology network design and optimization platform. It works from initial design to densification and optimization. A simulator is selected because it has the following features:

- Multi technology tool Dedicated Project Templates & Propagation models for all supported technology
- User friendly GUI (Windows based tools, Easy to export/ import all required data and Simply support copy/paste), and
- Flexibility in data management Display, Sorts & Filter.

Digital Map

The most important basic preparatory requirement for radio propagation model is a geographical map of the planning area. The map is needed in coverage (link loss) predictions and subsequently the link loss data are utilized in the detailed calculation phase and for analysis purposes. For network planning purposes, a digital map should include at least topographic data (terrain height), morphographic data (terrain type, clutter type) and building location and height data, in the form of raster maps.

In addition, it is important to include data for building locations in digital maps. If available, road information (raster or vector) can also be used in certain operations, such as traffic modeling and coverage predictions. A raster unit (map resolution) is usually in the range of 1 up to 200 m.

Site Layout

After importing the maps into the Atoll program we started by selecting the Area of planning which was chosen according to the distribution of population. Atoll includes integrated single RAN - multiple RAT network design capabilities for both 3GPP (GSM/UMTS/LTE) and 3GPP2 (CDMA/LTE) technology streams. It provides operators and vendors with a powerful framework for designing and optimizing current and future integrated multi-technology networks. Atoll supports the latest technology advances such as HetNets and small cells.

Figure 5-1: Site layout for Adama city (Atoll simulation software)

Computation Zone

The computation zone is used to define which base stations are to be taken into consideration in calculations and the area where ATOLL calculates path loss matrices, coverage studies, etc. When we create a computation zone, Atoll carries out the calculation for all base stations that are active. Thus the computation zone that shows in figure 5-2 allows us to restrict our coverage prediction result of radio frequency propagation model to the part of the network we are currently working on.

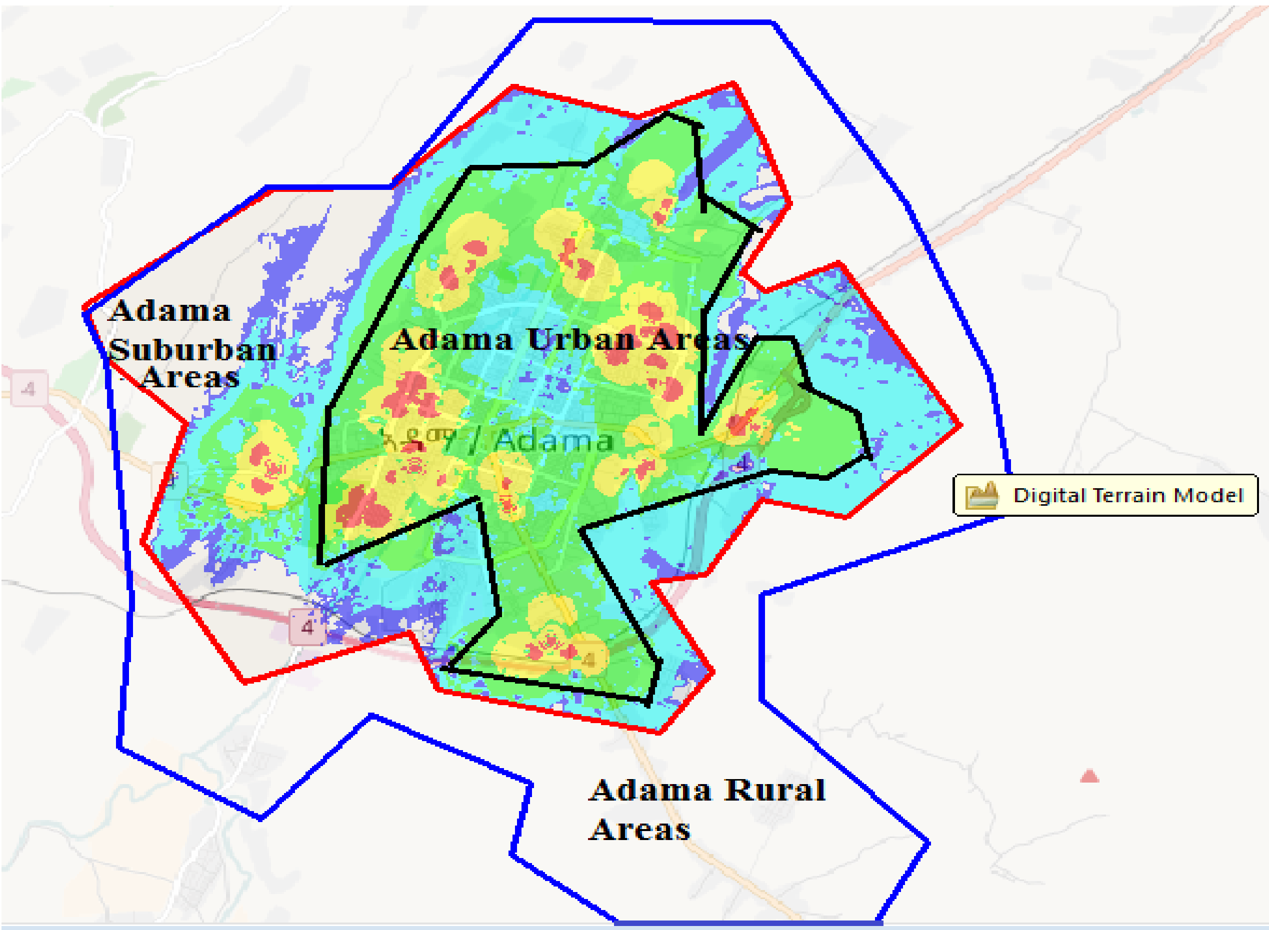


Figure 5-2: Adama city urban, suburban and rural computational zone (coverage)

5.2 Experimetal Details

Measurement-based Prediction (MbP) is a unique radio propagation process, which increases the accuracy of conventional propagation model predictions by making use of measured data to improve the model predictions around base station sites. The measurements were conducted from a

UMTS network with WCDMA interface transmitters, located urban areas (around Adama tele, tesfaye olompic building the road between Mebirat Hayil and post office, Dashen bank the road between post office and Franco and Adama Menehariya around Fronco, suburban areas (around Sekekelo at the back of Gendehara to Gendegara at the back of Adama university/Chelenko mender and rural areas (around Adulala to Wonji road), all evenly distributed Adama city. The drive routes in these different locations are shown in figure 5-3, 5-8, 5-14. The measured received signal strength data which is the Received Signal Code Power (RSCP) and transmitter to receiver (T-R) separation distance (d) are recorded in dBm and m. Every measurement points of received signal strength and T-R separation distance are recorded evenly from all the predefined routes of the twelve base stations.

Each measurement point is represented in an average of a set of samples taken over a small area in order to remove the effects of fast fading. The Nemo-Analyzer cell planner tool for data collection with the handy (mobile phone that have this software for data collection), during drive test we should wrote a script for the received voice or data and the software by itself has its own GPS to provide the location tracking for the system during data collection, on Actix Analyzer which has been installed on the personal computer and on this software all the data's (such as: RSCP, SC, Tx power for the mobile, EC/NO, EFS, distance from the starting point to the endpoint, time………etc) have been exported to excel and Google earth.

The Nemo analyzer helps to determine the various azimuth angles of the base station transmitters. Average height of transmit antenna is above ground level, with the same transmit power. Sampling rate of the collected data, on the average, is about 2 – 3 samples per meter. The exported data from the Actix-analyzer is imported to Google Earth to get the path, distance from the base station and the mobile when doing our drive test; then by using a ruler the RSCP data at various distances (every sample) from the BS were determined from the Google Earth. This technique enabled us to calculate the Electric Field Strength (EFS) and pathloss at different distances from the BS. At this distance from the base station and calculated the Path Loss for different radio frequency propagation models. The results of the calculated pathloss are shown in Tables A1-A4, B1-B4 and C1-C4 for urban, suburban and rural areas, respectively in the appendix.

The actual path loss measurements can be analyzed relative to the empirical models to see whether these propagation models are accurate to be used for path loss prediction in the study area. By taking readings at various distances, it is possible deduce some conclusions about the performance of the base station transmitter. The path loss increases as the received field signal decreases and this implies a decreases quality of service. The measured received signal strength data which is the Received Signal Code Power (RSCP) and transmitter-receiver (T-R) separation distance (d) are recorded in dBm and m from the drive test and compared with the calculated path loss of radio frequency propagation models for each sites with the perspective areas of study (urban, suburban and rural) areas in Adama city.

The figure below shows the site layout and measurement route of **urban areas** (from Adama tele to Wonji Mazoria) from the Google Earth.

Figure 5-3: Measurement route from Adama tele to Wonji Mazoria (Urban area)

Figure below the analysis of the stated parameters on MapInfo (from Actix analyzer) and Nemo-analyzer (data collection software) in **urban area**.

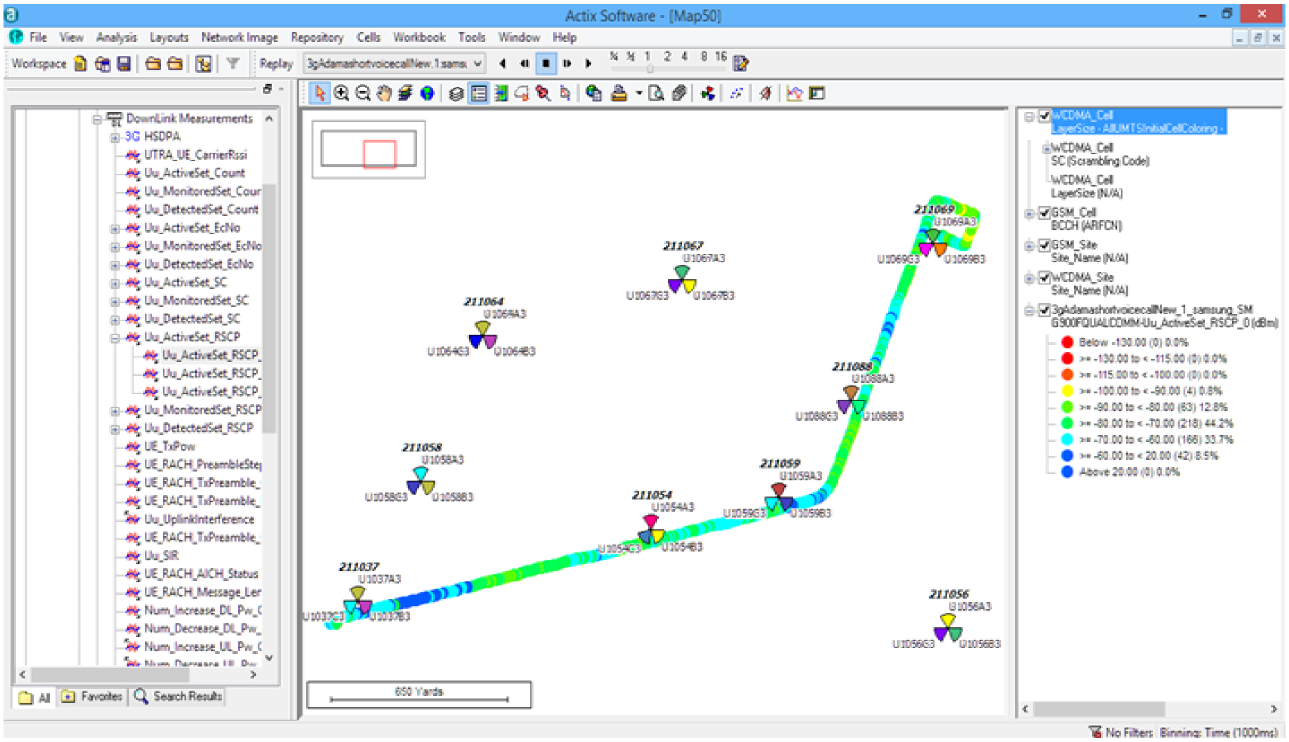


Figure 5-4: Analysis of RSCP on Mapinfo

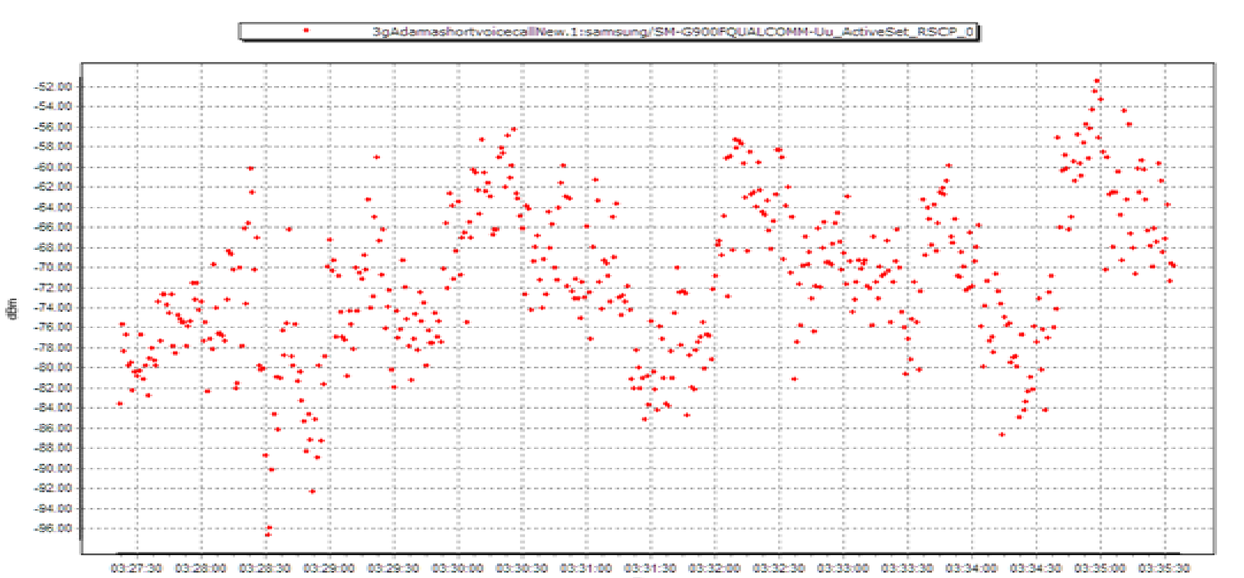
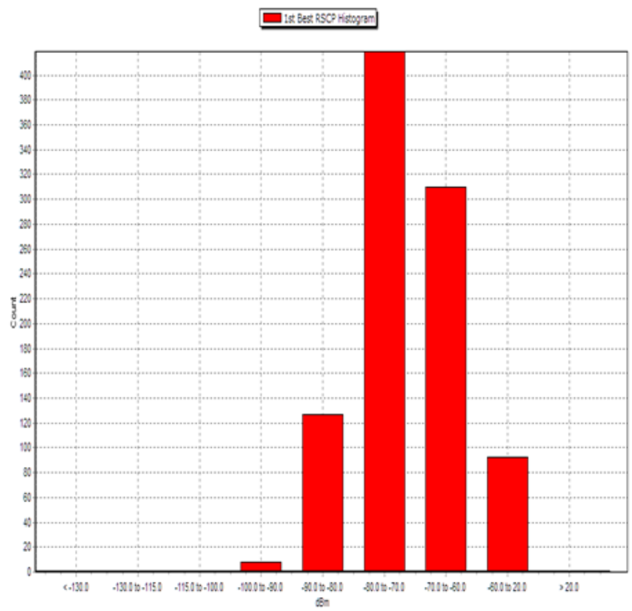
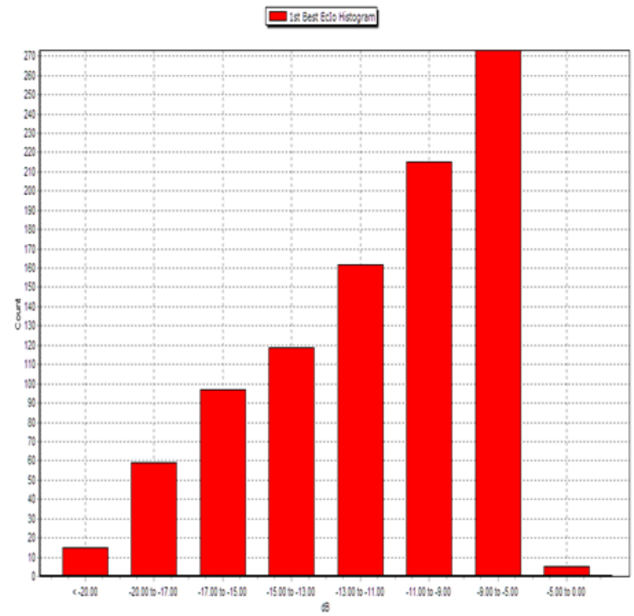


Figure 5-5: sampled RSCP Vs Time graph for urban areas

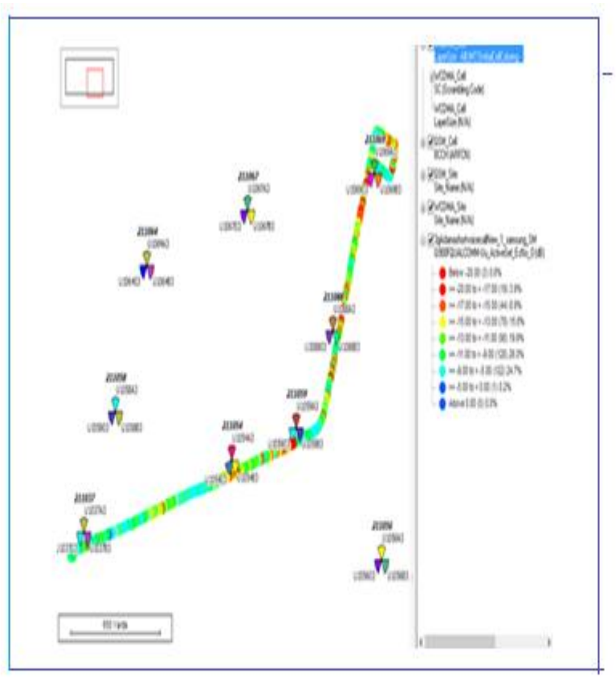


(a)

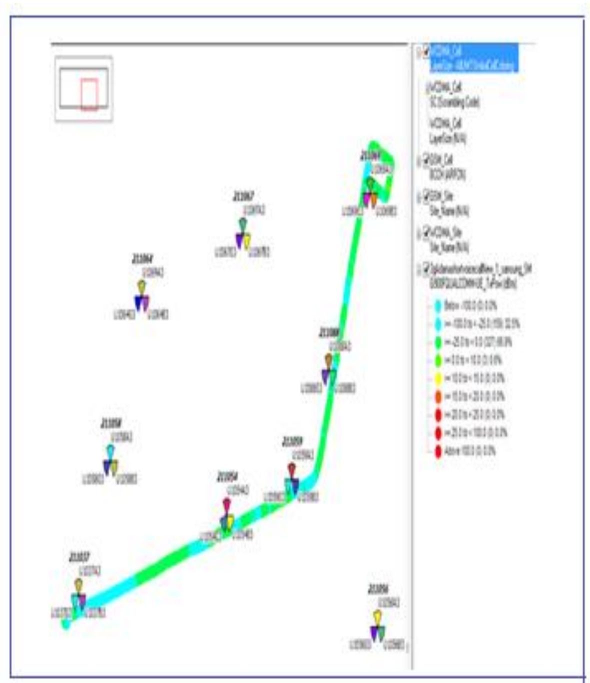


(b)

Figure 5-6: Bar chart depicting the ranges and counts of the RSCP level (a) and EC/NO Level (b)



(a)



(b)

Figure 5-7: Analysis of Active EC/NO (a) and Ue_Tx_power (b) on Mapinfo

The Figure below shows the site layout and measurement route of **suburban areas** (from Sekelelo to Amede Kela) from the Google Earth.

Figure 5-8: Measurement route from Sekekelo to Amede Kela (suburban area)

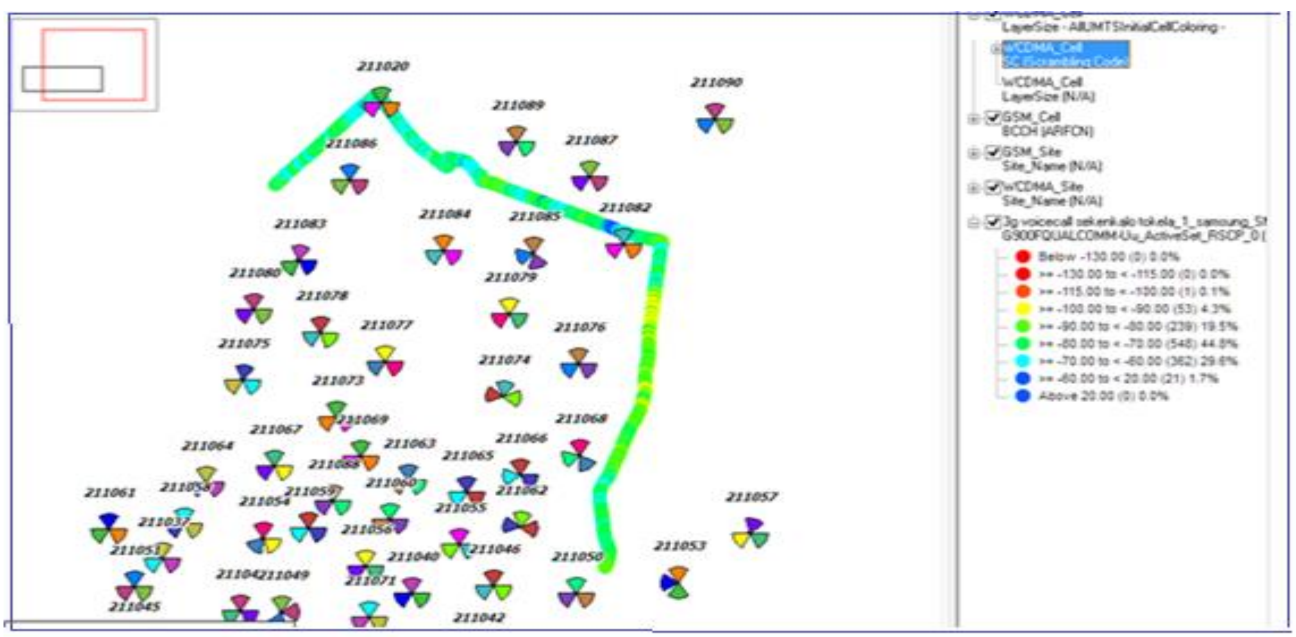


Figure 5-9: Analysis of RSCP on Mapinfo

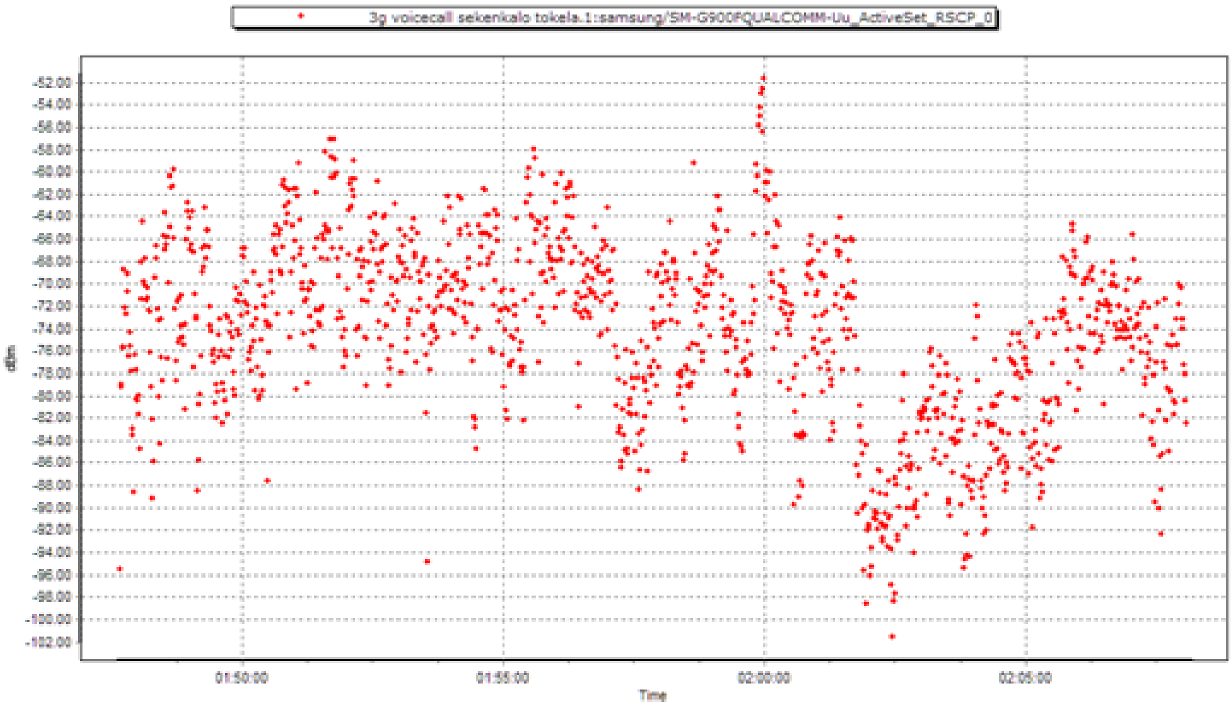
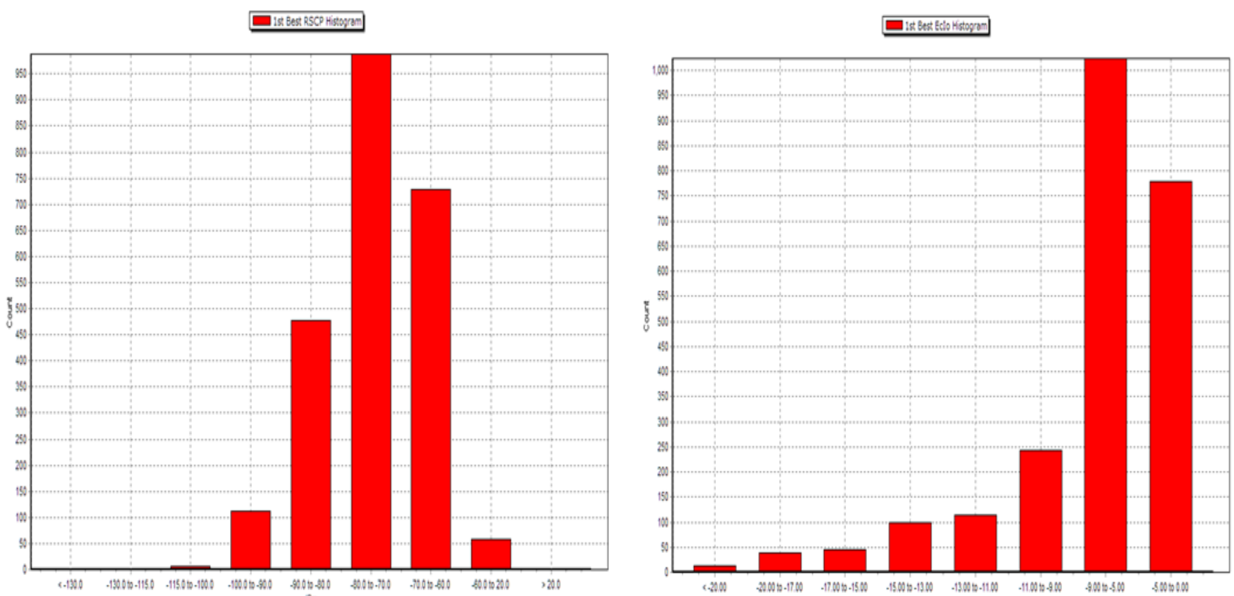


Figure 5-10: Sampled Vs RSCP graph for Suburban areas



(a) (b)

Figure 5-11: Bar chart depicting the ranges and counts of the RSCP level (a) and Ec/No level (b)

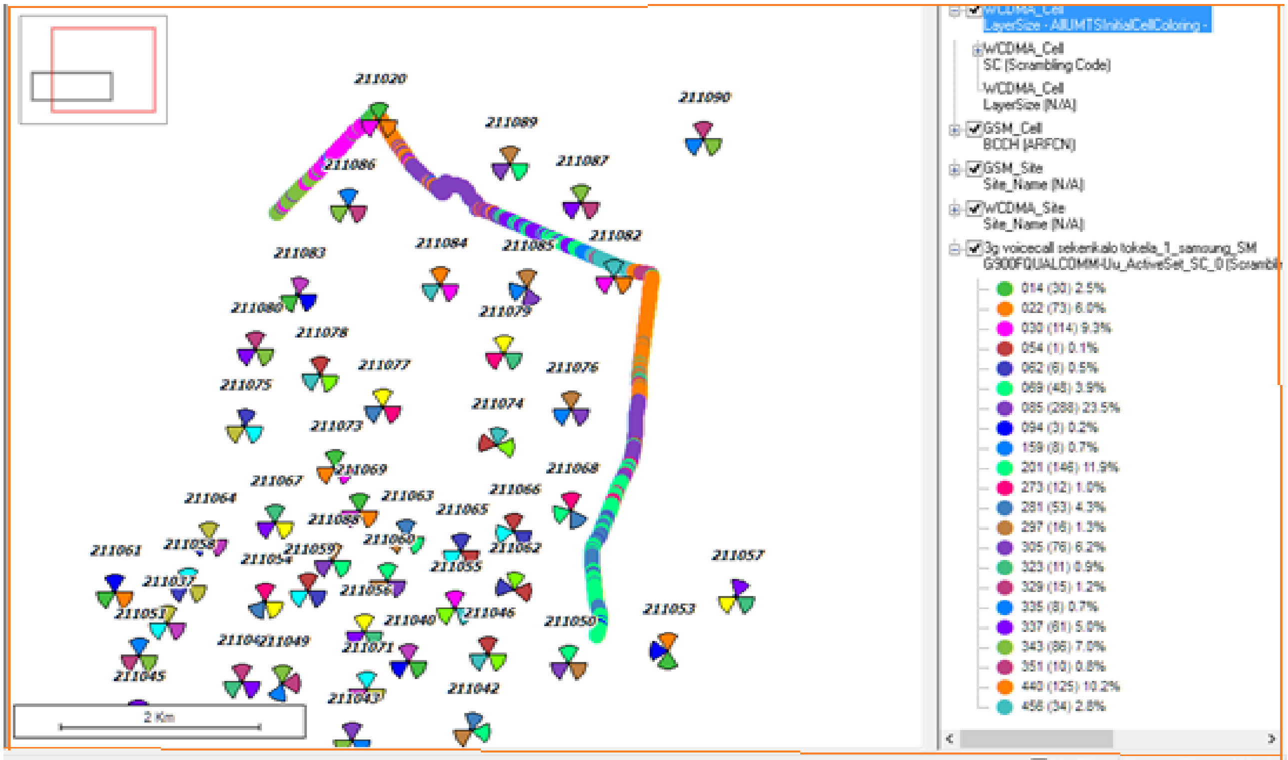


Figure 5-12: Analysis of Active Ue_Tx_power on Mapinfo

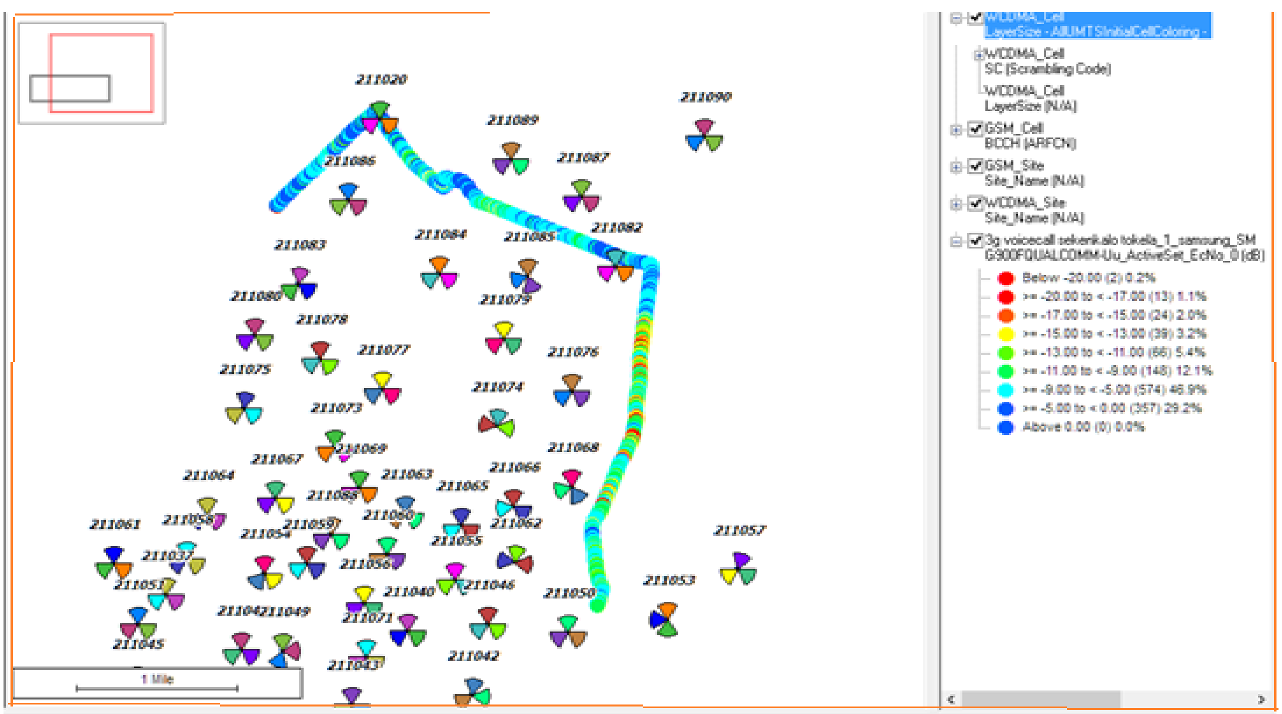


Figure 5-13: Analysis of Active EC/NO on Mapinfo

The Figure below shows the site layout and measurement route of **rural areas** (from Adulala to Wonji Road) from the Google Earth.

Figure 5-14: Measurement route from Adulala to Wonji road (rural area)

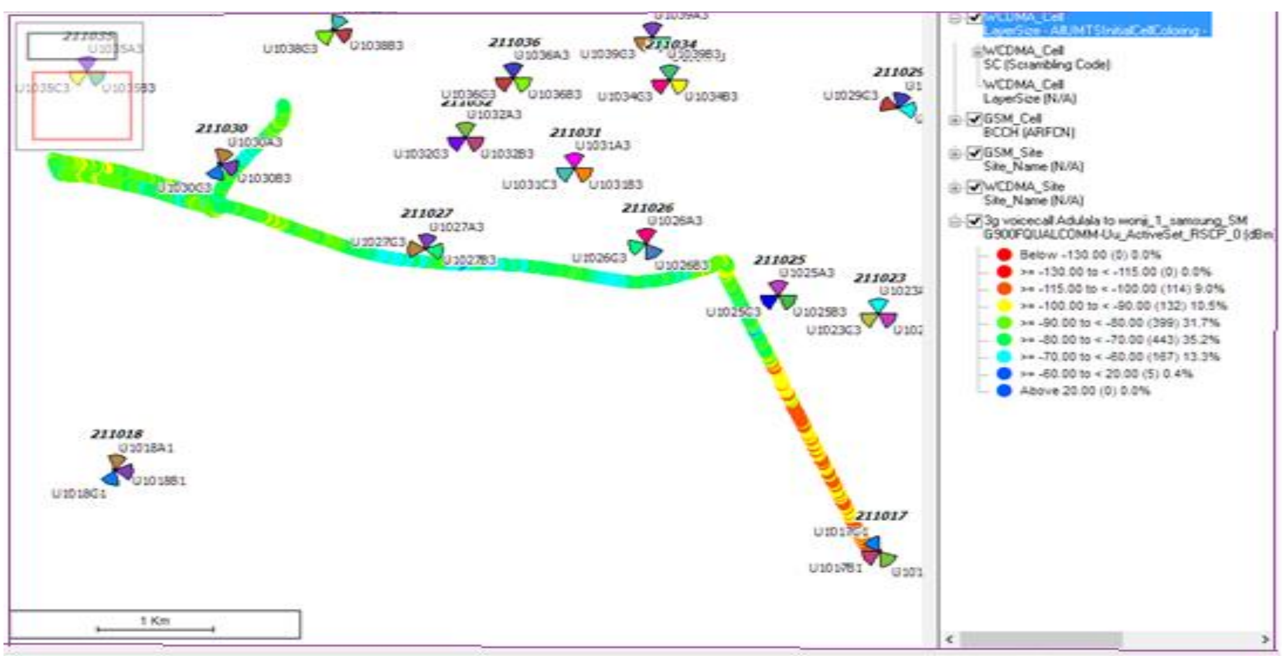


Figure 5-15: Analysis of RSCP on Mapinfo

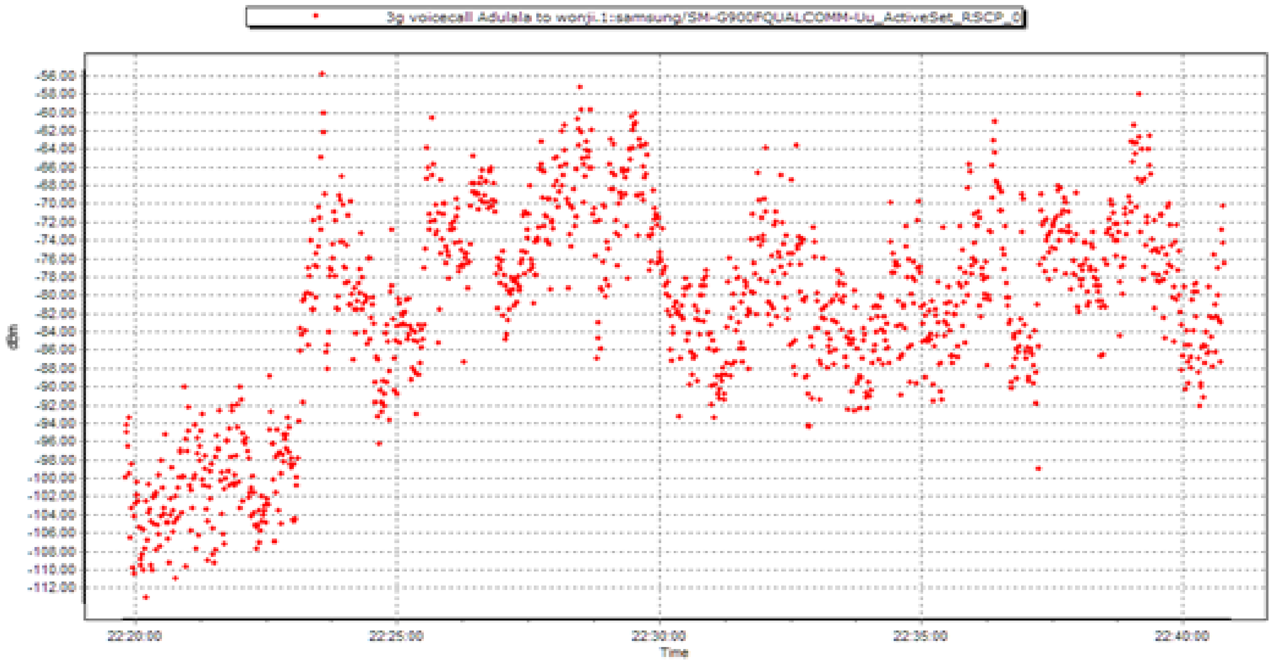
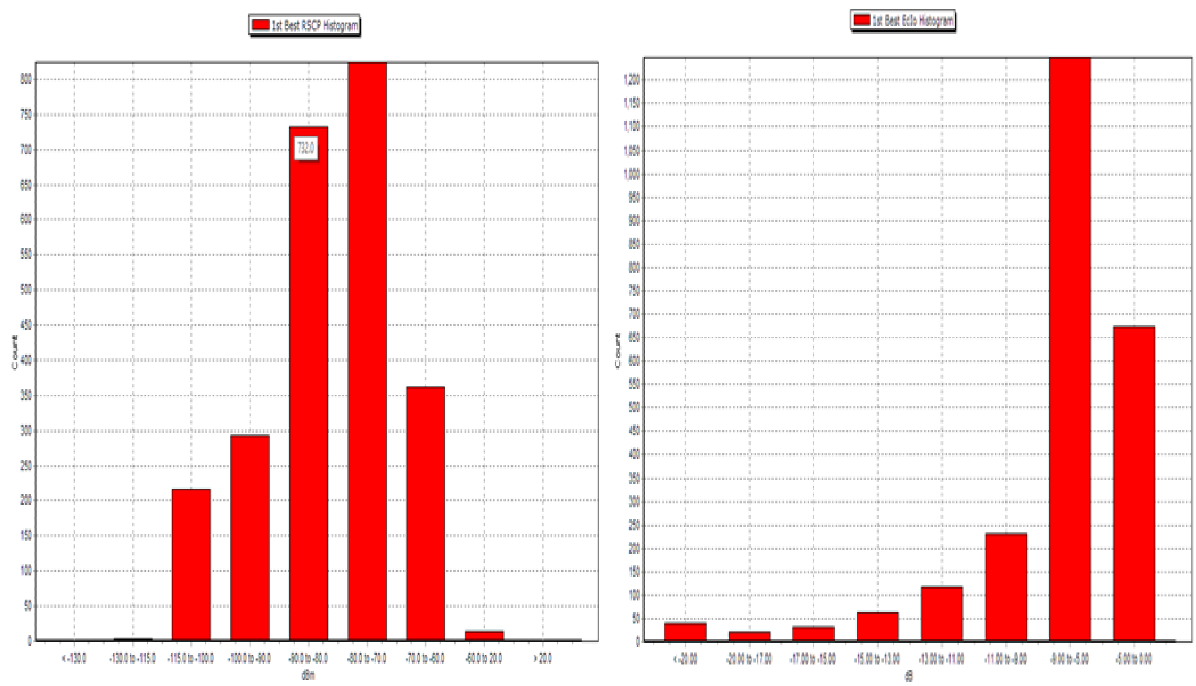


Figure 5-16: Sampled Vs RSCP graph for rural areas



(a) (b)

Figure 5-17: Bar chart depicting the ranges and counts of the RSCP level (a) and Ec/No level (b)

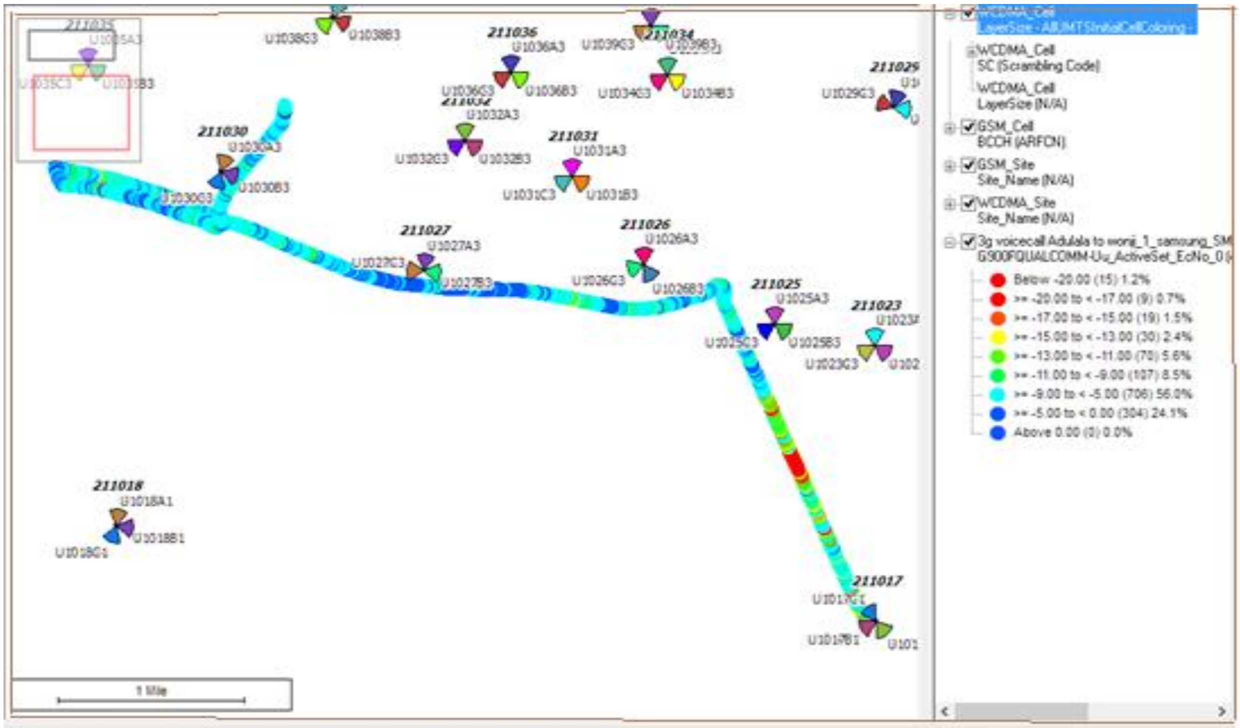


Figure 5-18: Analysis of Active EC/NO on Mapinfo

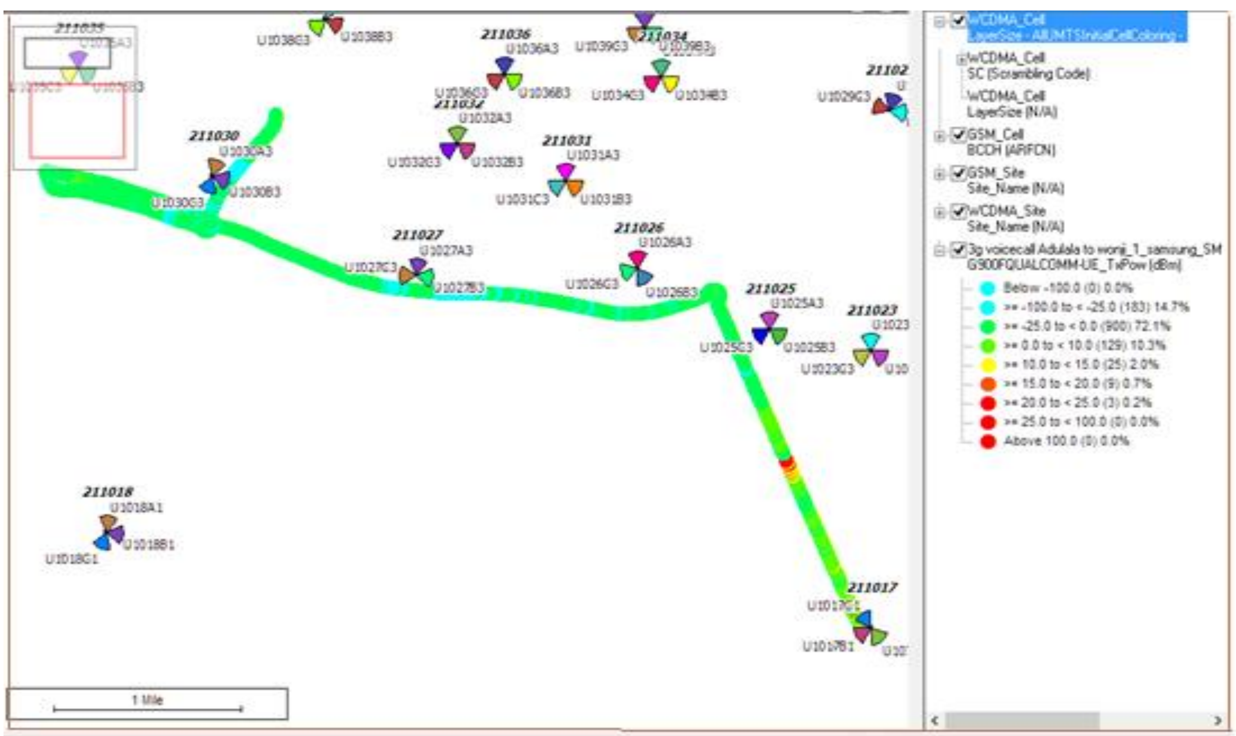


Figure 5-19: Analysis of Active Ue_Tx_power on Mapinfo

5.3 Calculation of path attenuation loss method from measured data

Based on the reception mode, the minimum equivalent field strength of a signal at a receiver can be calculated using the following formulas [16]:

$$P_{s\,min} = \frac{C}{N} + P_n \quad (5.1)$$

$$A_e = G + 10log\left(\frac{1.64\lambda^2}{4\pi}\right) \quad (5.2)$$

$$\emptyset_{min} = P_{s\,min} - A_e \quad (5.3)$$

$$E_{min} = \emptyset_{min} + 120 + 10\log(120\pi) = \emptyset_{min} + 145.8 \quad (5.4)$$

Where:

$P_{s\,min}$ = Minimum receiver input power {dBW}

A_e = Effective antenna aperture {dBm2}

G = Antenna gain {dB}

λ = wavelength of the signal {m}

$\emptyset_{min}$ = Minimum power flux density at receiving place {dB (W/m2)}

E_{min} = Equivalent minimum field strength at receiving place {dB(μV/m)}

P_n = Receiver noise input power {dBW}

120π = Characteristic Impedance in ohms

The electric field strength Emin (dBμV/m) is obtained from the experimental results. Taking *P*min from the above equations to be equivalent to the received power *PR* (*dB*) , the corresponding path loss can be obtained as follows;

$$P_T(dB) = 10\log P\,T\,(Watts) \quad (5.5)$$

$$P_T(Watts) = 20 \quad (5.6)$$

$$P_T(dB) = 43 \quad (5.7)$$

$$A_e = G + 10\log\left(\frac{1.64\lambda^2}{4\pi}\right) \quad (5.8)$$

Taking $G \approx 17dB$ for WCDMA Antenna (directional),

$$A_e = G - 25.75 = -7.75(dBm2) \quad (5.9)$$

The equation for path loss becomes:

$$PL\,(dB) = 166.\,51 - E\text{min} \quad (5.10)$$

5.4 Results and Discussion

The actual path loss measurements can be analyzed relative to the empirical models to see whether these propagation models are accurate to be used for path loss prediction in the study area. The path loss calculation parameters for all of the study areas (urban, suburban and rural areas) include the following:

Table 5-1: simulation Parameters

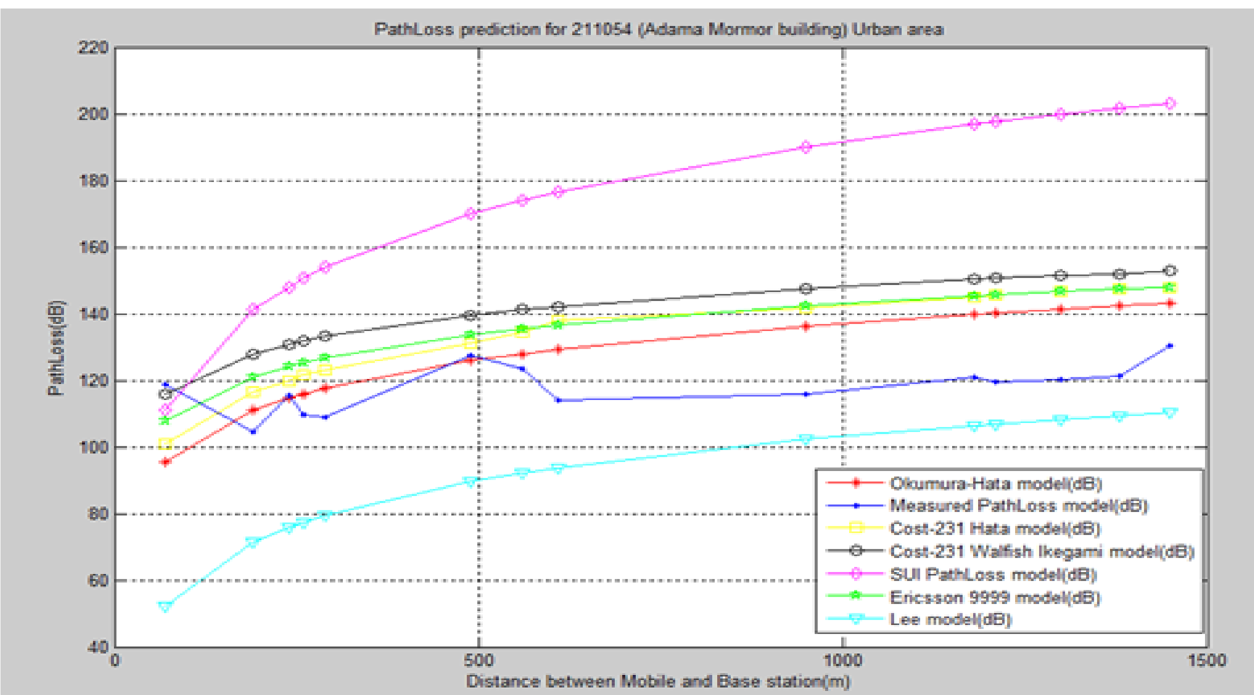
Parameters	**Values**	
Base station transmitter power	43 dBm	
Mobile Transmitter power	3G	(21-24) dBm
	2G	(30-33) dBm
Transmitter antenna height (BS) (m)	211054	22
	211059	28
	211069	26
	211088	28
	211020	27
	211089	37
	211087	41
	211082	37
	211023	30
	211025	30
	211026	35
	211027	30
Receiver antenna height (m)	1.2	
Correction for shadowing	In suburban and rural (8.2 dB) and In urban area (10.6 dB)	
Operating frequency	2100 MHz	
Distance between Transmitter and Receiver	It depends on the measurement	
Average Building to Building distance (m)	Urban	5
	Suburban	20

Average building height (m)	Urban	15
	Suburban	20
Street width (m)	Urban	16
	Suburban	12
Street Orientation angle (Ѳº)	Urban	35-40
	Suburban	45-55
Transmitter antenna gain (dBi)	15-17	

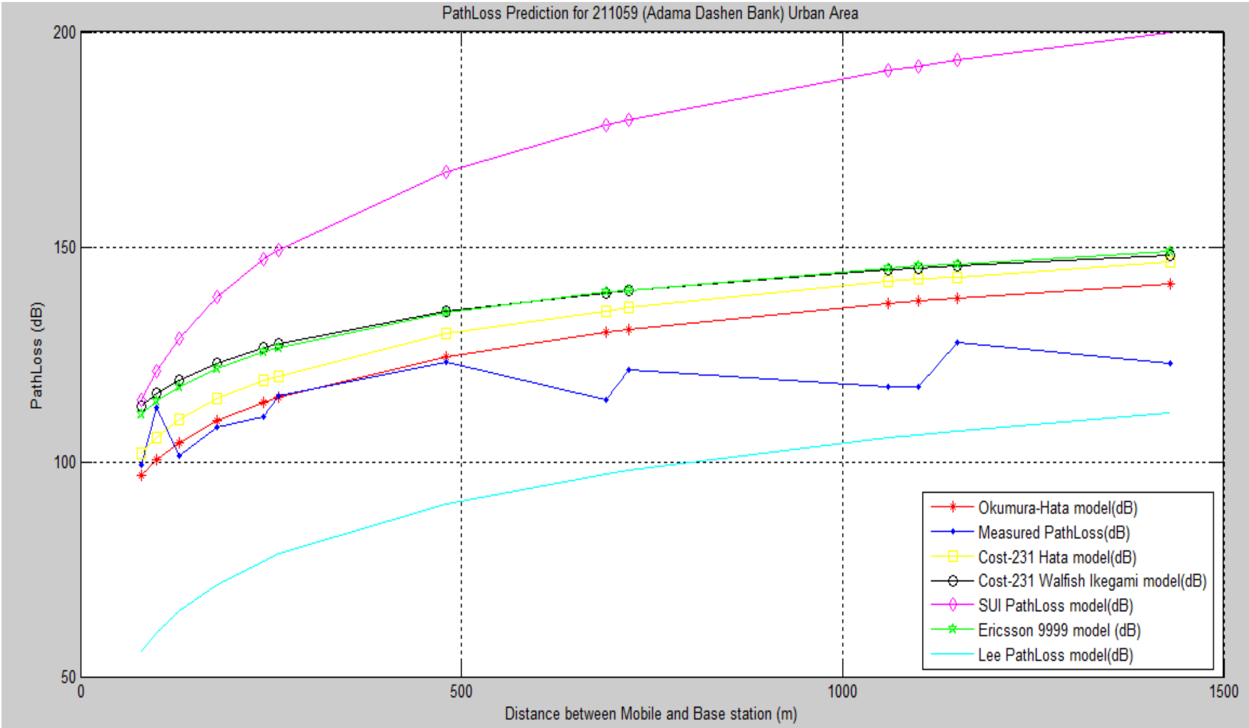
By taking readings at various distances, it is possible deduce some conclusions about the performance of the base station transmitter. The path loss increases as the received field signal strength decreases and this implies a decreases quality of service. The reason for such performances may attribute to factors as discussed previously.

5.4.1 Simulation Results of Urban Areas

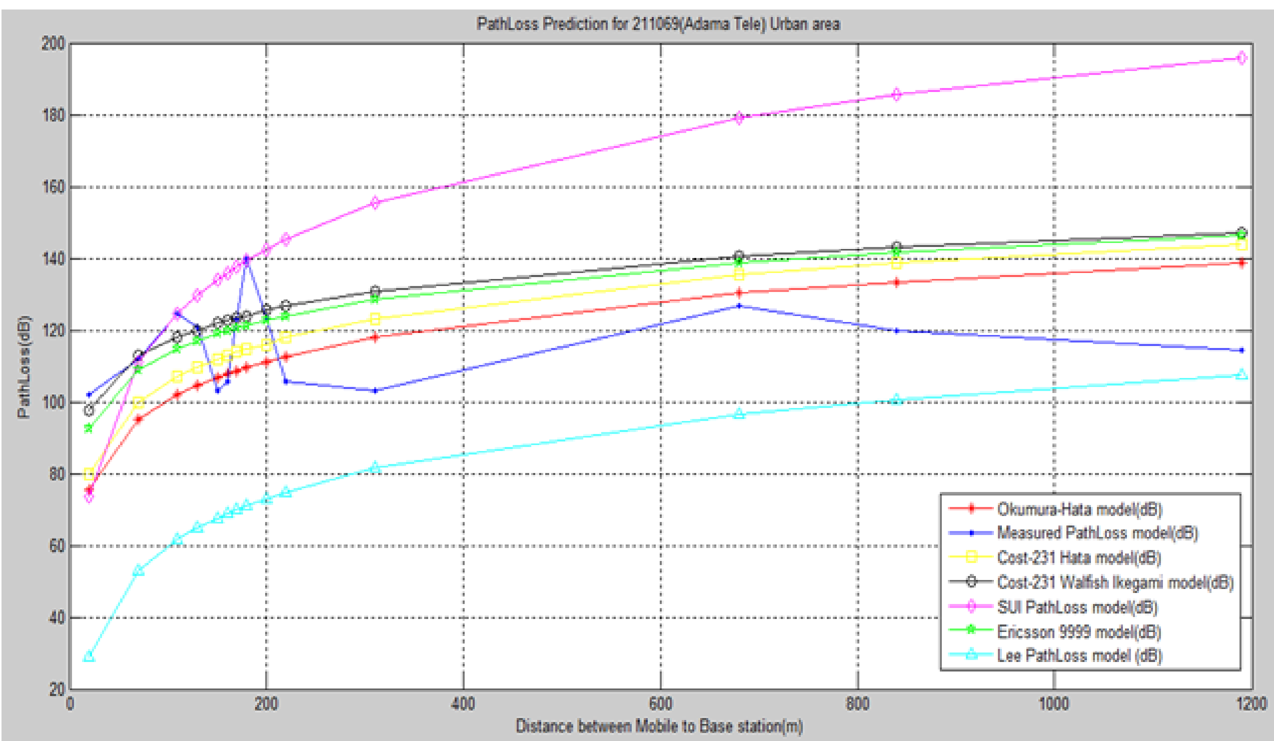
Figure 5-20 below gives simulation results for the path loss versus distance for each Node B in urban areas and the results of the simulation is taken from the table in the appendix A1-A4.



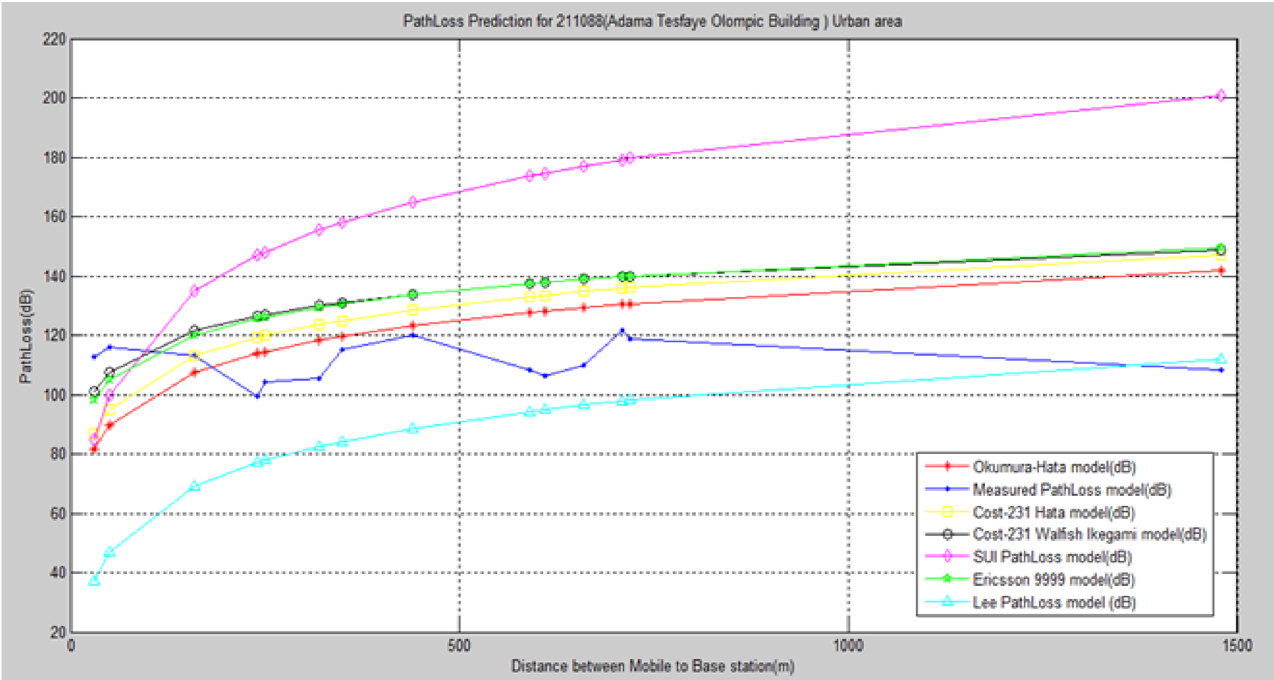
(a)


PathLoss Prediction for 211059 (Adama Dashen Bank) Urban Area
PathLoss (dB)
Distance between Mobile and Base station (m)
Okumura-Hata model(dB)
Measured PathLoss(dB)
Cost-231 Hata model(dB)
Cost-231 Walfish Ikegami model(dB)
SUI PathLoss model(dB)
Ericsson 9999 model (dB)
Lee PathLoss model(dB)

(b)


PathLoss Prediction for 211069(Adama Tele) Urban area
PathLoss(dB)
Distance between Mobile to Base station(m)
Okumura-Hata model(dB)
Measured PathLoss model(dB)
Cost-231 Hata model(dB)
Cost-231 Walfish Ikegami model(dB)
SUI PathLoss model(dB)
Ericsson 9999 model(dB)
Lee PathLoss model (dB)

(c)



(d)

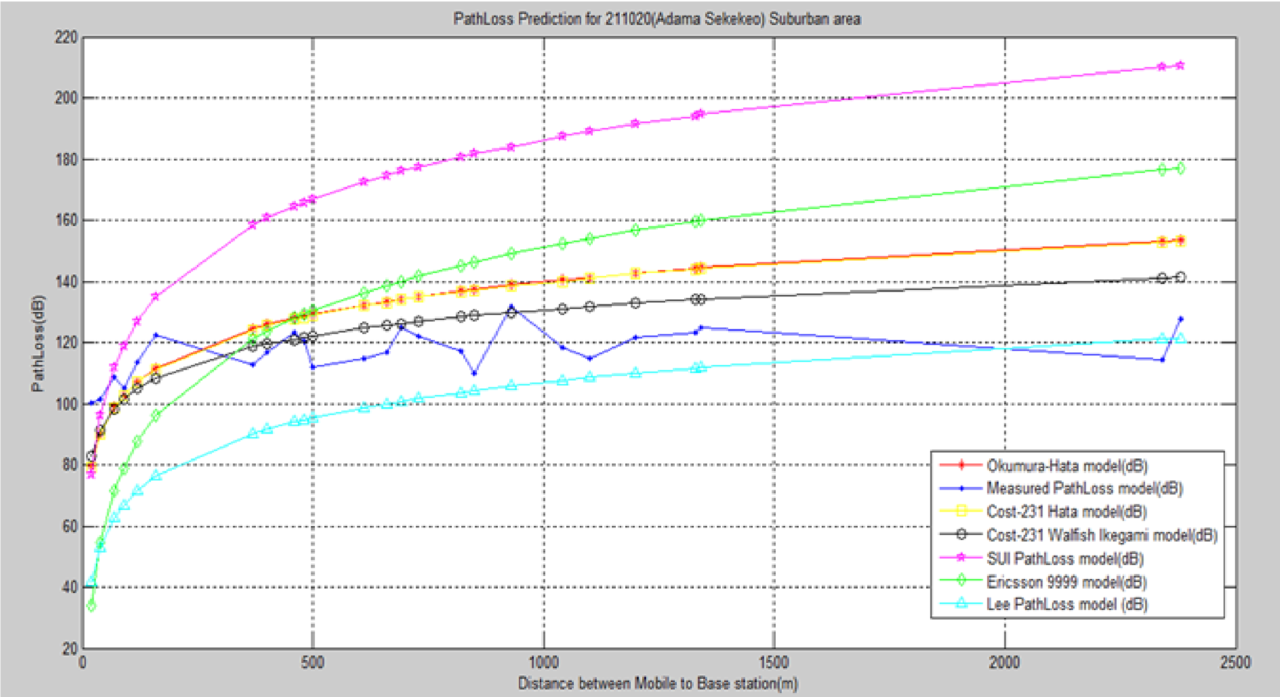
Figure 5-20: Path attenuation loss (dB) analysis for an urban area with respect to distance (m) (a, b, c, d)

Figs.5-20 above show the path loss at various distance of from the BS for an urban area (around Adama tele, Adama Tesfaye olompic building, Adama Dashen bank and Adama cinema mormor building) in comparison other existing path attenuation calculation models. From the graphs, the following observations can be made:

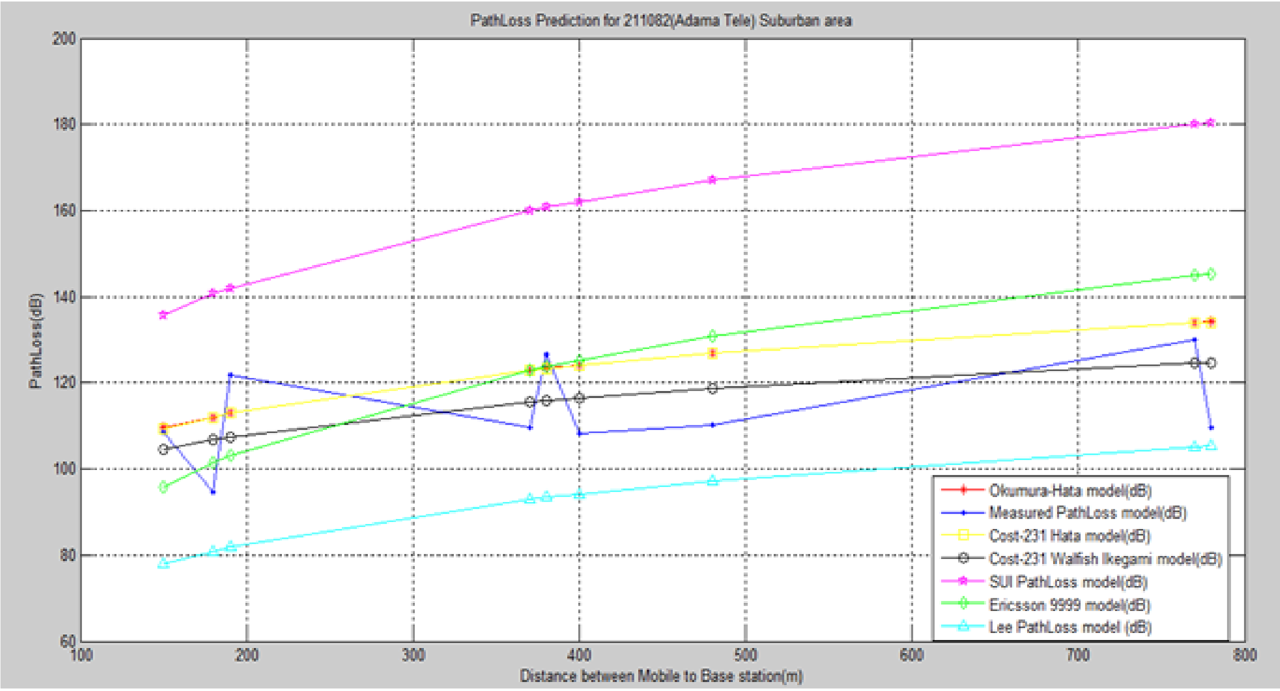
The Lee model somewhat the least (underestimates) path loss while the SUI path loss model slightly overestimates the path loss. The sudden up at distance 180 m (211069) can be a sharp turn around a building in this particular location, thus path loss could have been influenced by diffraction over the surface. The other deviations (ups and downs) are normally the cause of shadowing, reflection, diffraction or scattering, most probably due to the presence of buildings. The Okumura-Hata model is observed to be the closest model to the measured value. Also the measured graph is somewhat close to the Lee model for the distance above 500 m but this model works for rural areas with the operating frequency of 900 MHz and not working for urban areas because for the coming 2 or 3 years the rural area of Adama become urban or suburban area.

5.4.2 Simulation Results of Suburban Areas

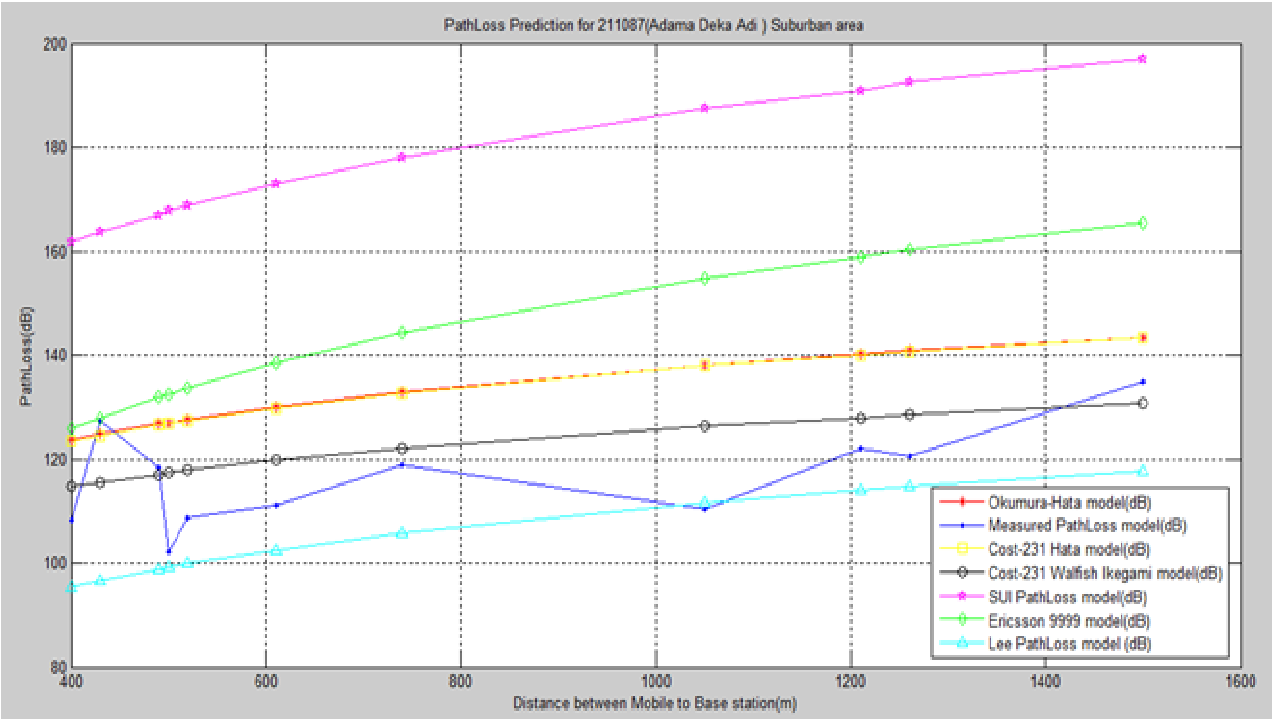
Figure 5-21 below gives simulation results for the path loss versus distance for each Node B in Suburban areas and the results of the simulation is taken from the table in the appendix B1-B4.



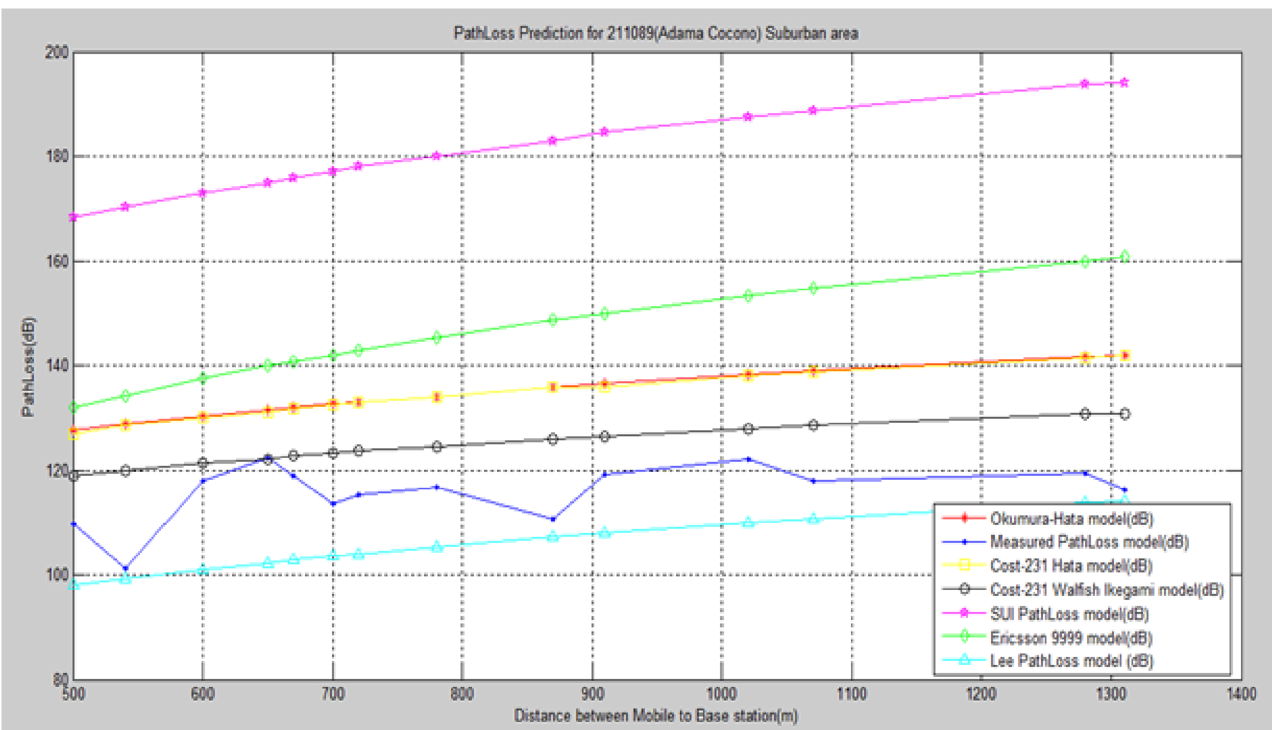
(a)



(b)



(c)



(d)

Figure 5-21: Path attenuation loss (dB) analysis for a Suburban area with respect to distance (m) (a, b, c, d)

The following can be deduced from the graph for the Suburban area in Figure 5-21:

It is observed that the measured value experienced quite stability with zero fluctuation from distance 1.07 km to about 1.28 km for the site 211089. This may be attributed to an almost clear line of sight (LoS) between the transmitter antenna and the receiver antenna.

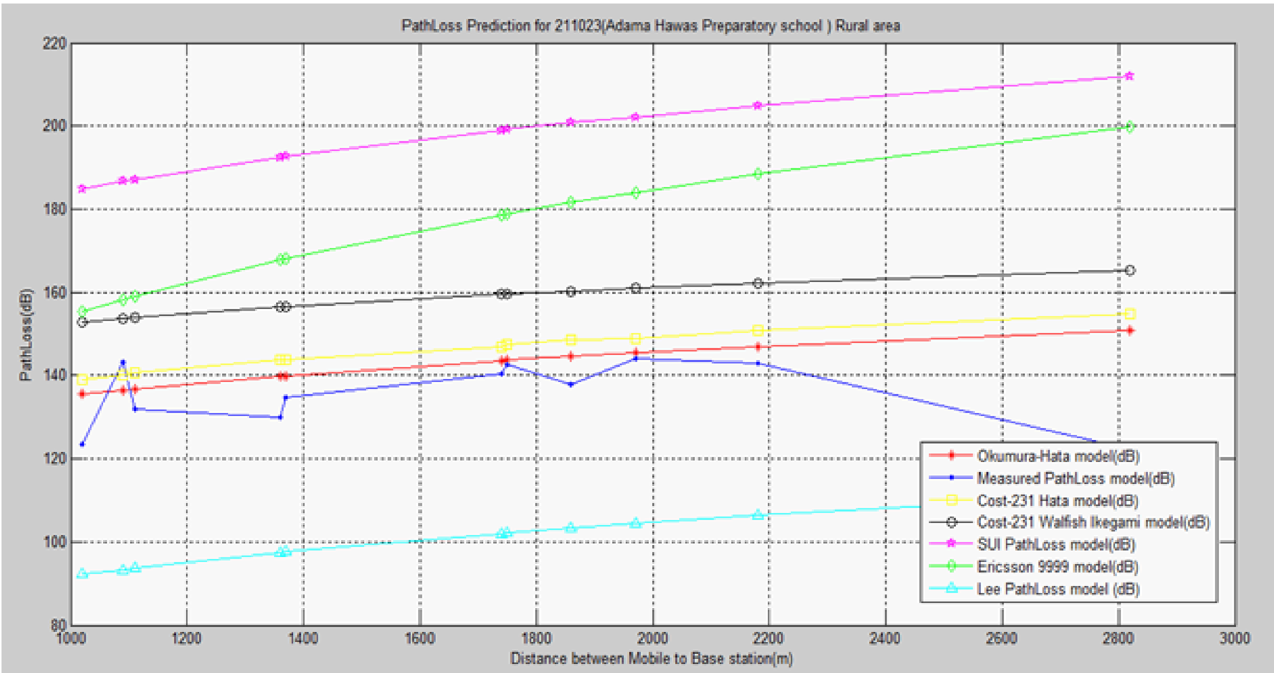
The Lee model again underestimates the path loss but with less variation from the urban areas. This can be attributed to the fact that this model takes into consideration the effective base station antenna height which is highly dependent on the exact topology of the measurement environment. The COST-231 Walfish-Ikegami model is observed to be the closest model to the measured value. This can be attributed to the fact that this model is originally suitable for urban macrocells, when fc is within 0.8 GHz – 2 GHz, h_r is within 1 – 3m and d is between 0.02-5 km. The Okumura model closely follows the COST-231 Hata model in proximity to the measured data for this particular location. This is because the COST-231 Hata model is an extension of the Okumura model to 2 GHz, and they both have the same specifications for BS antenna height above 30 m, and can also be used when h_t is less than 30 m provided the buildings in the region are well below 30 m.

The Okumura-Hata or the COST-231 Hata model can be used as an estimate for Path loss for the suburban region. The deviations can be considered as negligible. The Okumura-Hata model is independent of Receiver antenna height hence the path loss for this particular region in experiment is also independent of the antenna heights. Also the measured graph is somewhat close to the Lee model for the distance above 800 m but this model works for rural areas with the operating frequency of 900MHz and not working for suburban areas.

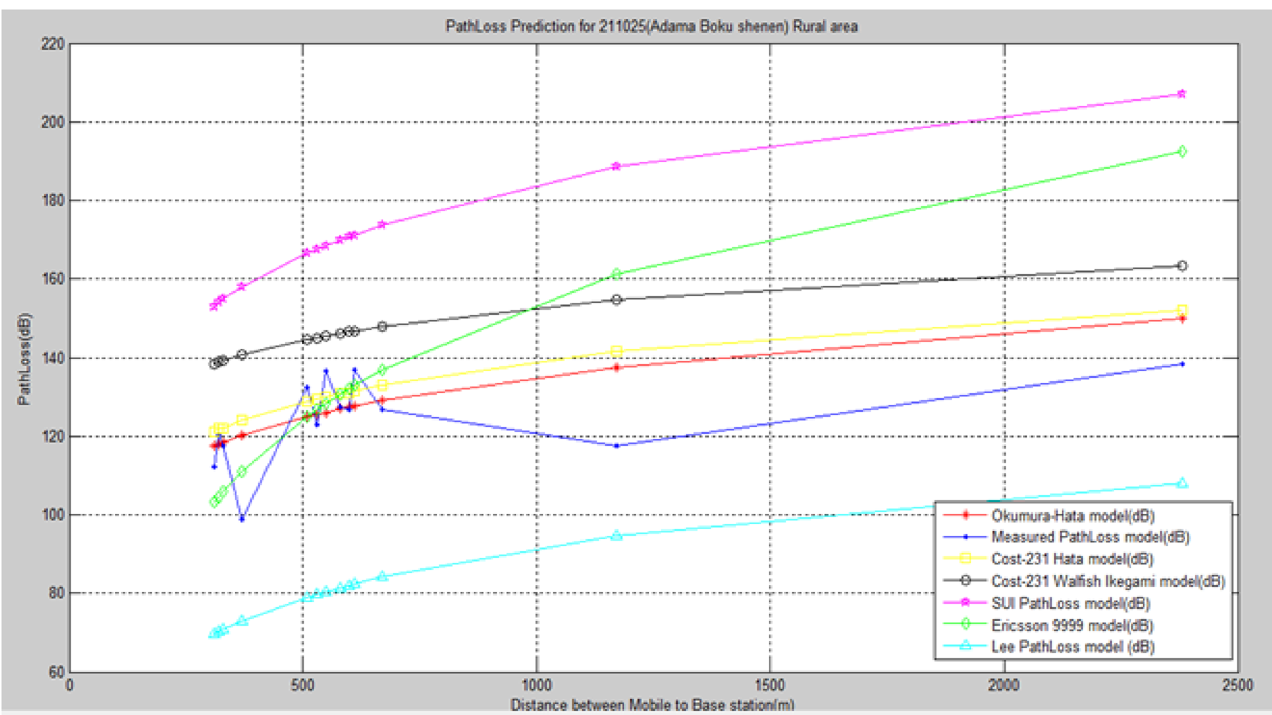
The variation in the experimental values (non-straight line graph) can be attributed to the Suburban environment having many obstructions in the path, like buildings in close proximity, as well as trees sandwiched in between houses.

5.4.3 Simulation Results of Rural Areas

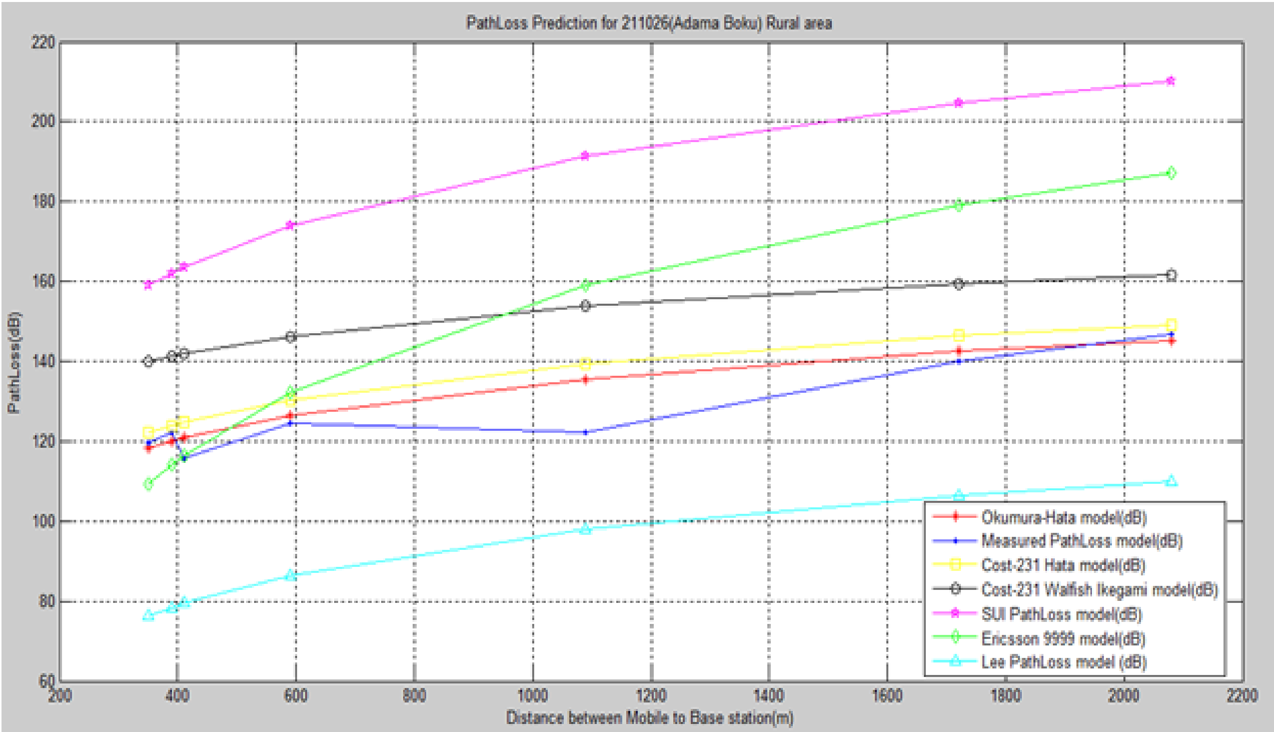
Figure 5-22 gives simulation results for the path loss versus distance for each Node B in rural areas and the results of the simulation is taken from the table in the appendix C1-C4.



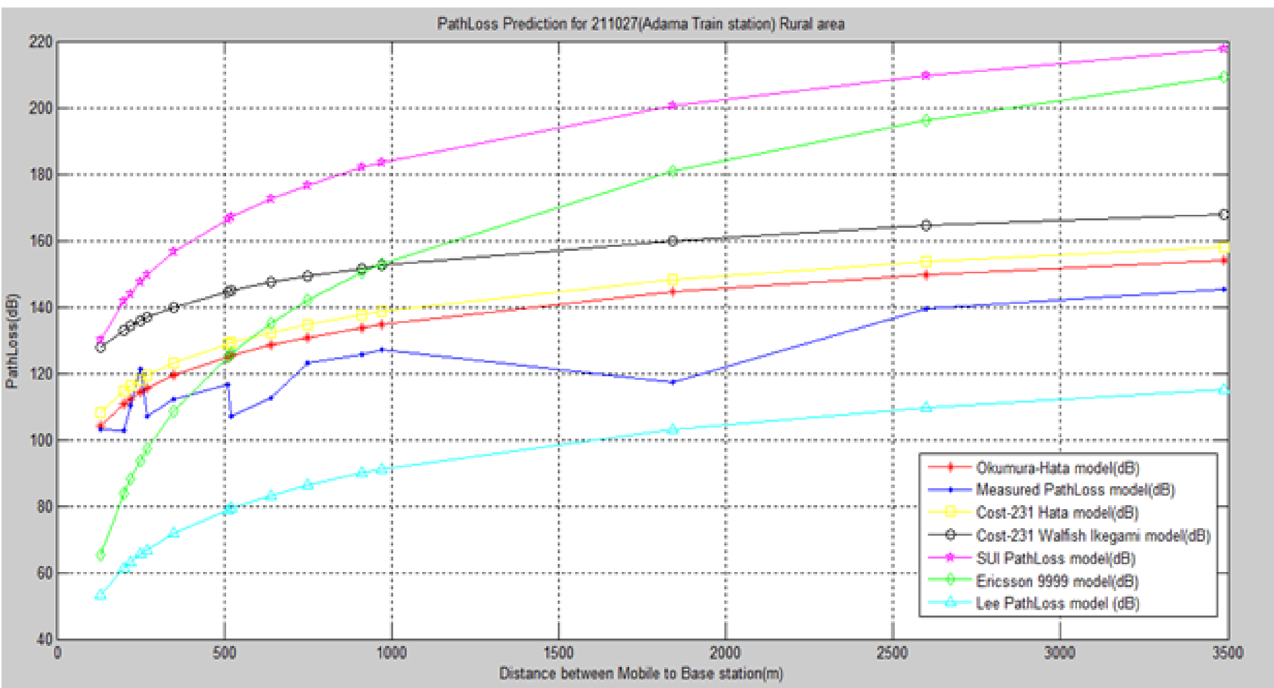
(a)



(b)



(c)



(d)

Figure 5-22: Path attenuation loss (dB) analysis for a rural area with respect to distance (m) (a, b, c, d)

From the graph in figure 5-22, the following observation has been made for rural environment; The Lee Model highly underestimates the path loss. This can be attributed to the fact that this model takes into consideration the effective base station antenna height which is highly dependent on the exact topology of the measurement environment.

The SUI model overestimates the losses most probably because it is designed basically for medium city or suburban areas. Again the Okumura-Hata model is observed to be the closest model to the measured value. As we observed from the simulation the measured graph is somewhat close to the Lee model but this model works for rural areas with the operating frequency of 900MHz and as we know Adama is one of the fastest growing cities of the country and for the coming 2 or 3 years the rural parts of the city will become suburban or urban, so this model is no more working in this area.

Moreover, mean path losses from the various prediction methods were also calculated and compared with measured field data to validate the choice of Okumura-Hata model for the studied area. The results are shown in figures 5-23 - 5-25.

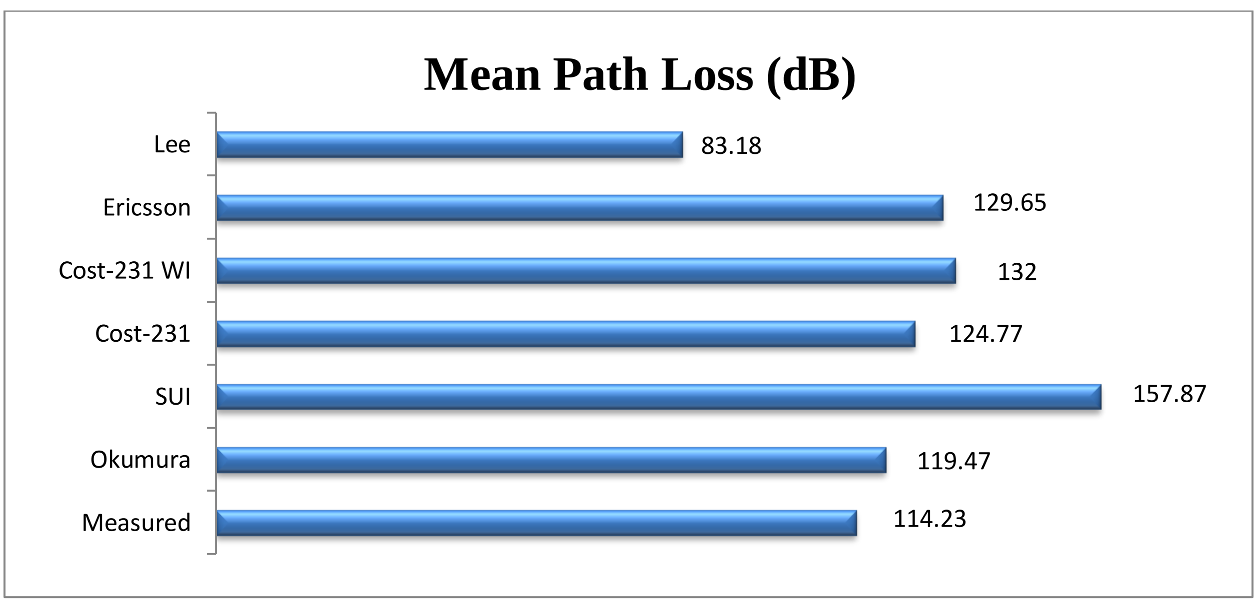


Figure 5-23: Calculated mean path attenuation loss from the various prediction models in comparison with measured field data in Urban Areas

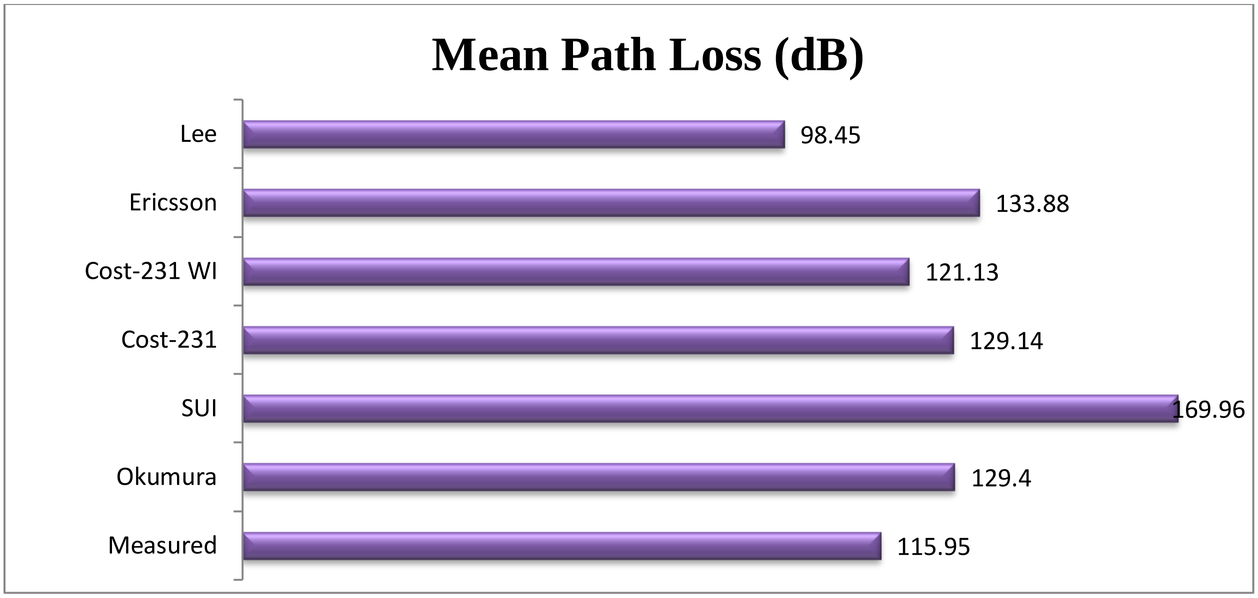


Figure 5-24: Calculated mean path attenuation loss from the various prediction models in comparison with measured field data in Suburban environment

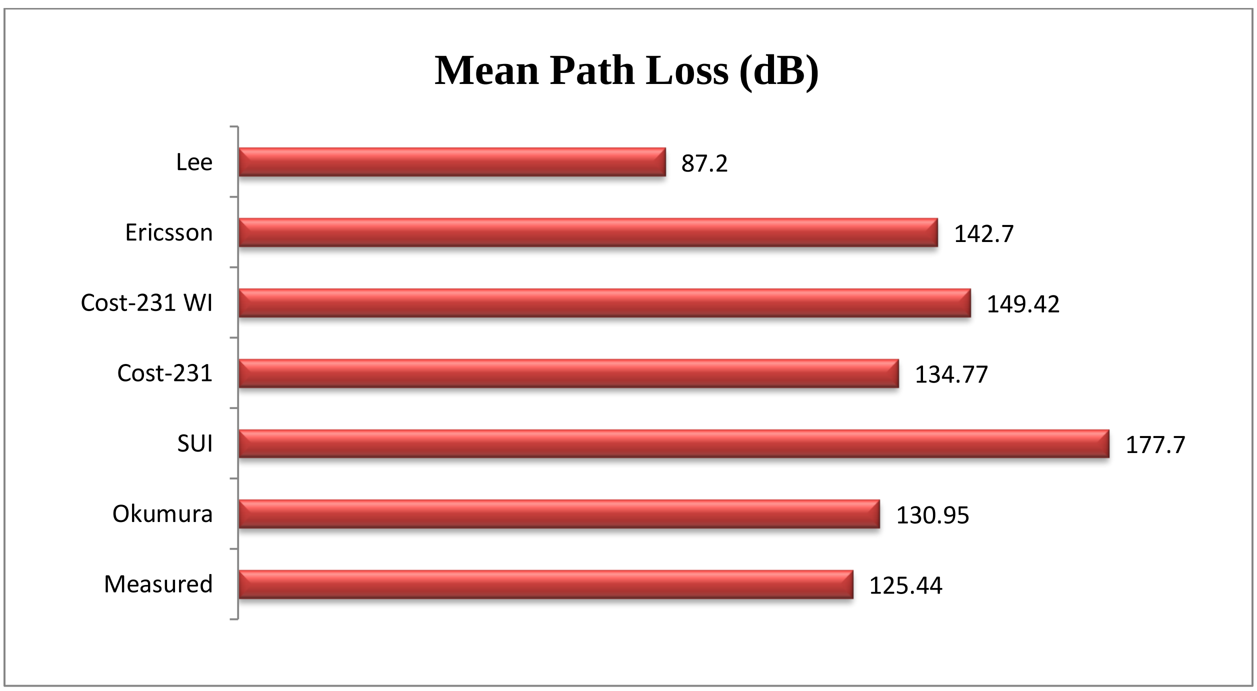


Figure 5-25: Calculated mean path attenuation loss from the various prediction models in comparison with measured field data in rural areas

Chapter Six

6 Conclusion and Future Work

6.1 Conclusion

Propagation modeling is an effort to predict what happens to signals on route from the transmitter to the receiver. The accurate qualitative understanding of the radio propagation using path loss model as a function of distance from where the signal level could be predicted is essential for reliable mobile wireless system network plan. If network planning is carried out with the help of a network planning system then coverage planning, frequency planning, capacity planning, interference analysis, dominance analysis, handover analysis, etc. rely on the propagation predictions.

Though propagation models are available to predict the losses, they are not very accurate in determining the coverage area of a system. This is due to the fact that these models have been designed based on measurements elsewhere. Therefore, in-field measurements must support the path loss prediction models for better and accurate results. This study aims at conducting field strength measurement to calculate the path loss in a UMTS network operating in urban, suburban and rural areas in Adama city. The measured field strength data collected over different distances from the base stations was used to estimate the path loss.

The observed results have been compared with various prediction methods. The thesis found that the Okumura-Hata model path loss values were closest of all the outdoor propagation models considered classifying the environment into consideration. Thus, the performance of Okumura-Hata model shows its suitability for path attenuation loss prediction in UMTS networks in Adama city, the effect of different parameters, such as distance from base stations was studied and it is observed that path loss increases with distance due to a corresponding decrease in field strength.

It also shows that model can be useful to telecommunication providers to improve their services for better signal coverage and capacity for mobile user satisfaction in the studied area.

In summary, results show that the obstructions in the environment considered here had little effect (not much) on radio signals.

6.2 Recommendation and Future Work

- The work of this thesis can be extended by considering a scenario in which LTE and LTE advance network are present and they are working interrelated in the selected area because radio propagation prediction is the basic for network planning after coverage and capacity planning.
- In future, the simulated propagation model results can be tested and verified practically in indoor environments.
- In future, cell planning in LTE network by using the propagation models that have traffic capacity and coverage features should be considered.
- Ethio-telecom used its own tuned radio propagation model for Ericsson network and for the future the researcher needs to study this tuned radio propagation model and develop their own tuned model using one of the best propagation model studied before.

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Appendix A

The measured and calculated path loss, RSCP and separation distance (Tx-Rx) each radio frequency propagation models for **urban, suburban and rural Areas**

Table A 1: Calculated and measured path loss, RSCP for 211054

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
70	-75.8	118.8	95.45	110.96	100.9	115.9	108	52.1
190	-61.5	104.5	111.1	141.3	116.5	128	121	71.3
240	-72.4	115.4	114.7	148	120	130.9	124.3	75.8
260	-66.6	109.6	116	150.8	121.5	131.88	125.3	77.35
290	-65.9	108.9	117.7	154	123	133.2	126.8	79.45
490	-84.3	127.3	125.96	170	131	139.5	133.7	89.54
560	-80.3	123.3	128	174	134.5	141.2	135.49	92.1
610	-70.9	113.9	129.4	176.7	137.88	142	136.6	93.76
950	-72.8	115.8	136.3	190	141.8	147.6	142.4	102.2
1180	-77.85	120.85	139.7	196.8	145	150.2	145.3	106.4
1210	-76.29	119.29	140.1	197.6	145.6	150.58	145.6	106.9
1300	-77.1	120.1	141.3	199.7	146.7	151.4	146.58	108.3
1380	-78.19	121.19	142.2	201.6	147.6	152	147.3	109.4
1450	-87.3	130.3	142.97	203.1	148	152.78	148	110.4

Table A 2: Calculated and measured path loss, RSCP for 211059

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
80	-56.2	99.2	96.96	114.3	102	113	111.1	55.88
100	-69.6	112.6	100.4	121	105.7	115.88	114	60.18
130	-58.4	101.4	104.4	128.7	109.8	119	117.5	65.16
180	-64.9	107.9	109.4	138.4	114.8	123	121.79	71.4
240	-67.45	110.45	113.8	147	119	126.5	125.58	76.9
260	-72.2	115.2	115.1	149.3	120	127.5	126.6	78.5
480	-80.25	123.25	124.5	167.5	129.8	134.95	134.7	90.3

690	-71.4	114.4	130.1	178.3	135	139.3	139.5	97.2
720	-78.5	121.5	130.7	179.6	136	139.88	140	98.1
1060	-74.4	117.4	136.7	191	142	144.58	145	105.5
1100	-74.5	117.5	137.3	192	142.6	145	145.6	106.2
1150	-84.7	127.7	137.96	193.5	143	145.58	146	107.1
1430	-79.9	122.9	141.32	200	146.6	148	149	111.3

Table A 3: Calculated and measured path loss, RSCP for 211069

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
20	-59.1	102.1	75.62	73.6	80	97.5	92.47	28.78
70	-68.9	111.9	95	111	99.99	112.75	108.97	52.88
110	-81.6	124.6	102	124.6	107	118	114.9	61.58
130	-77.9	120.9	104.6	129.6	109.6	120	117	64.8
150	-60.2	103.2	106.8	133.9	111.9	122	119	67.5
160	-62.6	105.6	107.8	135.8	112.9	122.8	119.87	68.8
170	-80.19	123.19	108.7	137.6	113.88	123.5	120.66	69.9
180	-96.7	139.7	109.6	139.4	114.78	124	121.4	71
200	-80.5	123.5	111.2	142.5	116	125.5	122.8	73
220	-62.7	105.7	112.7	145.4	117.9	126.67	124	74.9
310	-59.95	102.95	118	155.6	123	130.8	128.58	81.5
680	-83.8	126.8	130.2	179	135.6	140.4	138.9	96.6
840	-76.9	119.9	133.4	185.5	138.9	142.97	141.7	100.7
1190	-71.5	114.5	138.85	195.9	144	147	146.3	107.4

Table A 4: Calculated and measured path loss, RSCP for 211088

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
30	-69.7	112.7	81.8	85	87	101	98.2	37
50	-73.1	116.1	89.7	100	95	107.4	104.9	46.8
160	-70.1	113.1	107.6	134.9	112.99	121.5	120	69.2
240	-56.3	99.3	113.86	147	119	126.5	125.59	77
250	-61.2	104.2	114.5	148	119.8	127	126	77.8
320	-62.6	105.6	118.3	155.5	123.6	130	129.4	82.55

350	-72.1	115.1	119.67	158	125	131	130.56	84.2
440	-77.2	120.2	123.2	165	128.55	133.89	133.57	88.68
590	-65.1	108.1	127.7	173.7	133	137.4	137.4	94.3
610	-63.3	106.3	128.21	174.7	133.5	137.87	137.88	94.97
660	-70.1	110.1	129.4	177	134.78	138.8	138.9	96.48
710	-78.8	121.8	130.55	179	135.9	139.7	139.88	97.89
720	-75.7	118.7	130.7	179.6	136	139.88	140	98.1
1480	-65.1	108.1	141.85	201	147	148.6	149.55	112

Table B 1: Calculated and measured path loss, RSCP for 211020

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
20	-57.1	100.1	79.5	76.6	79.3	83	33.85	41.5
40	-58.3	101.3	90.21	96	90	91.5	54.6	53.1
70	-65.7	108.7	98.87	111.8	98.7	98.3	71.4	62.5
90	-61.9	104.9	102.75	118.8	102.5	101.4	78.97	66.7
120	-70.5	113.5	107.2	126.9	107	104.9	87.6	71.5
160	-79.5	122.5	111.6	135	111	108.4	96.2	76.3
370	-69.7	112.7	124.6	158.5	124	118.6	121.37	90.3
400	-73.8	116.8	126	160.7	125.6	119.56	123.7	91.6
460	-80.1	123.1	128	164.6	127.77	121	127.9	93.96
500	-69.1	112.1	129.4	166.9	129	122	130.4	95.3
610	-71.7	114.7	132.3	172.5	132	124.7	136.3	98.68
660	-73.6	116.6	133.5	174.7	133	125.66	138.7	100
690	-81.8	124.8	134	175.99	134	126	140	100.7
730	-78.9	121.9	135	177.5	134.9	126.88	141.76	101.7
820	-74.3	117.3	136.9	180.8	136.7	128.3	145	103.6
850	-66.7	109.7	137.47	181.8	137	128.7	146.3	104.2
930	-88.6	131.6	138.8	184	138.6	129.8	149	105.7
1040	-75.5	118.5	140.5	187.5	140	131	152.3	107.6
1100	-71.7	114.7	141	189	141	131.87	154	108.5
1200	-78.7	121.7	142.8	191.5	142.5	132.9	156.67	109.9
1330	-80.4	123.4	144.4	194	144	134	159.75	111.7
1340	-81.7	124.7	144.5	194.6	144.3	134.3	159.98	111.8
2340	-71.3	114.3	153.1	210	152.89	141	176.7	121.1
2380	-84.8	127.8	153.4	210.7	153	141.25	177	121.4

Table B 2: Calculated and measured path loss, RSCP for 211082

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
150	-65.5	108.5	109.5	135.7	109.3	104.6	95.9	77.85
180	-51.7	94.7	112	140.7	112	106.8	101.4	80.9
190	-78.8	121.8	113	142	112.9	107.47	103	81.8
370	-66.5	109.5	123	160	122.9	115.58	123	92.9
380	-83.6	126.6	123.5	160.8	123.3	115.9	123.8	93.4
400	-65.3	108.3	124	162	124	116.5	125.3	94.2
480	-67.1	110.1	127	167	126.8	118.7	130.8	97.3
770	-86.9	129.9	134	180	133.9	124.5	145	105.2
780	-66.5	109.5	134.3	180.3	134	124.6	145.3	105.4

Table B 3: Calculated and measured path loss, RSCP for 211087

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
400	-65.3	108.3	123.8	161.8	123.5	114.7	125.88	95.5
430	-84.4	127.4	124.9	163.7	124.6	115.57	128	96.7
490	-75.5	118.5	126.8	167	126.6	117	131.97	98.89
500	-59.3	102.3	127	167.8	126.9	117.4	132.58	99.2
520	-65.7	108.7	127.7	168.8	127.5	117.88	133.75	99.88
610	-68.2	111.2	130	173	129.89	119.83	138.5	102.5
740	-75.8	118.8	133	178	132.77	122	144.3	105.8
1050	-67.4	110.4	138	187.6	137.98	126.4	154.8	111.6
1210	-79.1	122.1	140.3	191	140	128	159	114
1260	-77.6	120.6	140.9	192.5	140.7	128.6	160.3	114.7
1500	-91.8	134.8	143.5	197	143.3	130.77	165.5	117.6

Table B 4: Calculated and measured path loss, RSCP for 211089

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
500	-66.8	109.8	127.6	168.3	127	119	132	97.98
540	-58.1	101.1	128.8	170.3	128.6	120	134.3	99.2
600	-74.9	117.9	130.3	173	130	121.4	137.5	101
650	-79.2	122.2	131.5	175	131	122	139.9	102.3
670	-75.9	118.9	132	176	131.8	122.8	140.8	102.9
700	-70.5	113.5	132.7	177	132.5	123.3	142	103.6
720	-72.3	115.3	133	178	132.9	123.67	142.99	104
780	-73.8	116.8	134	180	134	124.6	145.4	105.4
870	-67.7	110.7	135.98	183	135.78	125.9	148.66	107.2
910	-76.2	119.2	136.6	184.5	136	126.5	150	107.9
1020	-79.1	122.1	138.3	187.5	138	127.9	153.4	109.9
1070	-74.9	117.9	139	188.8	138.89	128.5	154.87	110.7
1280	-76.5	119.5	141.8	193.7	141.5	130.67	160	113.7
1310	-73.3	116.3	142	194	141.9	130.9	160.9	114

Table C 1: Calculated and measured path loss, RSCP for 211023

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
1020	-80.5	123.5	135.5	184.9	139	152.77	155.3	92.2
1090	-100.2	143.2	136.5	186.7	140	153.8	158.2	93.2
1110	-88.9	131.9	136.7	187	140.7	154	159	93.6
1360	-86.9	129.9	139.8	192.5	143.77	156.5	167.95	97.47
1370	-91.8	134.8	139.95	192.7	143.88	156.6	168.2	97.6
1740	-97.4	140.4	143.56	199	147	159.5	178.7	102
1750	-99.7	142.7	143.65	199.2	147.5	159.57	178.98	102.2
1860	-94.9	137.9	144.57	200.9	148.5	160.3	181.65	103.4
1970	-101.2	144.2	145.4	202	149	161	184	104.4
2180	-99.8	142.8	146.97	205	150.89	162.2	188.6	106.4
2820	-79.2	122.2	150.8	211.9	154.77	165.3	199.86	111.2

Table C 2: Calculated and measured path loss, RSCP for 211025

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
310	-69.2	112.2	117.5	153	121	138.5	103.2	69.69
320	-77.1	120.1	117.98	154	121.9	138.9	104.6	70.2
330	-74.6	117.6	118.4	154.9	122	139.3	105.99	70.86
370	-55.9	98.9	120.1	157.9	124	140.6	110.99	73
510	-89.4	132.4	125	166.5	128.9	144.58	125	79
530	-79.9	122.9	125.6	167.5	129.5	145	126.7	79.75
550	-93.7	136.7	126	168.5	130	145.5	128.3	80.4
580	-84.4	127.4	126.97	169.9	130.9	146	130.66	81.4
600	-83.7	126.7	127.48	170.8	131	146.55	132	82
610	-93.9	136.9	127.7	171	131.6	146.75	132.87	82.4
670	-83.9	126.9	129	173.7	133	147.9	136.97	84.1
1170	-74.4	117.4	137.57	188.5	141.5	154.68	161.37	94.6
2380	-95.3	138.3	150	207	152	163.3	192.4	107.9

Table C 3: Calculated and measured path loss, RSCP for 211026

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
350	-76.6	119.6	118.4	159	122.3	140	109.3	76.4
390	-79.3	122.3	120	162	123.98	141.3	114	78.4
410	-72.9	115.9	120.8	163.6	124.7	141.9	116.3	79.4
590	-81.5	124.5	126.3	174	130.2	146.3	132.2	86.3
1090	-79.2	122.2	135.5	191.5	139.5	153.8	159	97.9
1720	-96.9	139.9	142.47	204.6	146.4	159.3	179	106.5
2080	-103.7	146.7	145.3	210	149	161.67	187.3	110.1

Table C 4: Calculated and measured path loss, RSCP for 211027

Distance of Mobile from BS (m)	RSCP (dBm)	Measured Pathloss (dB)	Okumura Hata Path Loss Model	SUI Path Loss	Cost-231 Hata model	Cost-231 Walfish-Ikegami Model	Ericsson 9999 Model	Lee model
130	-60.2	103.2	104.3	130	108.3	127.96	65.2	53.1
200	-59.8	102.8	110.89	141.6	114.8	133	84	61.2
220	-67.2	110.2	112.3	144	116.2	134.3	88.2	63
250	-78.3	121.3	114.2	147.5	118	135.9	93.8	65.47
270	-64.1	107.1	115.4	149.6	119.3	136.8	97.2	66.9
350	-69.2	112.2	119.3	156.5	123.2	140	108.56	71.83
510	-73.5	116.5	125	166.5	128.95	144.58	125	78.9
520	-64.2	107.2	125.3	167	129.2	144.8	125.88	79.3
640	-69.7	112.7	128.4	172.5	132.3	147.3	134.97	83.2
750	-80.2	123.2	130.85	176.7	134.78	149.2	141.9	86.2
910	-82.7	125.7	133.77	181.9	137.7	151.6	150.3	89.88
970	-84.2	127.2	134.7	183.6	138.67	152.4	153	91
1840	-74.3	117.3	144.4	200.6	148.3	160	181	103.1
2600	-96.3	139.3	149.6	209.8	153.5	164.4	196.3	109.7
3490	-102.3	145.3	154	217.6	158	167.97	209.2	115.2